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PARTHENOCARPY OF PEARS AND APPLES

By CHRISTINE J. GORTER and T. VISSER
Laboratorium voor Tuinbouwplantenteelt, Landbouwhogeschool, Wageningen

(Publication No. 151)

FROM 1948–55 a series of experiments was carried out to investigate the production of parthenocarpic pomaceous fruits. Observations were made on vegetative parthenocarpy and on the influence of auxins and frost.*

Twenty-one varieties of apples and the same number of pears were used for these experiments, which gave a general insight into the ability of these varieties to set parthenocarpically under Dutch climatic conditions.

Reviews on parthenocarpy have been published by Skoog (10), Audus (1), Leopold (4), Van Overbeek (8), Nitsch (5). The present state of knowledge about this phenomenon, which is important both from a theoretical and from a practical point of view, may be best represented by quoting some of the specialists in this field.

In Skoog's " Plant growth substances " (10), Gardner (p. 219) classes parthenocarpy under the " problems needing solution ", and Wittwer (p. 375) points out that "One of the most puzzling series of reports is the failure of the known growth substances in effecting fruit set on such tree fruits as the apple, pear, peach, plum and cherry ". The latter also (p. 367) states that " To date an almost total disregard of the importance of prevailing weather in determining fruit setting response to hormone chemicals has left a confused and somewhat distorted picture, making it extremely difficult to interpret many of the contradictory reports." The same holds true for parthenocarpic fruit setting. Some confusion exists in the use of the term " parthenocarpy " which is often used for " seedlessness ". Seedlessness, however, could be a result of early embryo-abortion.

Originally Noll (6) used the word " parthenocarpy " for fruits which had developed without pollination. Later on it was used for fruits that developed without fertilization. The difference is significant because pollination itself provides a stimulus for fruit growth. It is impossible for the pollen grains to be the direct source of auxins for the growing ovary, because the relatively small quantity of auxin which is present either in living or in dead pollen grains is in no proportion to the auxin content of the developing ovary. It is an admissible assumption that a stimulus (auxin or other) from the pollen grains induces an enzymatic conversion of some precursor to auxin in the pistil and the ovary.

In parthenocarpic fruits, in which fertilized ovules are absent and no pollination has occurred, some other source of auxin must provide the fruit with the factors (hormones) necessary for development. In most fruits this source is still unknown. In the tomato, auxins are found in the flesh of the fruit, in the placenta and in the exocarp. In pomaceous fruits, however, the fruit flesh develops from the receptacle so that they are not comparable with tomatoes.

* " Auxin " as defined in " Nomenclature of chemical plant regulators " (Report by a Committee of the American Society of Plant Physiologists): *Plant Physiology*, **29**, 1954, 307–8.

It may be pointed out here that in parthenocarpic fruits ovules are also present, though unfertilized. They nevertheless sometimes grow, but sooner or later degenerate. Gustafson (3) showed for *Citrus* that the young ovules of seedless fruits contained much more auxin than the ovules of seeded fruits. He concluded that the auxin present in the ovules of seedless fruits was sufficient stimulus to start the enzymatic conversion necessary for fruit growth. With this theory of the auxin content of the ovules in mind, one could make the hypothesis that in parthenocarpic fruits the ovules degenerate later than in the normal fruits.

The term *natural parthenocarpy* is a misnomer and should be replaced by *natural seedlessness*. Parthenocarpy can only be investigated in experiments, when all possibility of fertilization has been excluded. The following definitions may then be given :

Parthenocarpy : setting and growth of fruits without the influence of fertilized ovules (pollination not excluded).

Vegetative parthenocarpy : parthenocarpy without pollination or any other externally supplied stimulus.

Stimulative parthenocarpy : parthenocarpy induced by some stimulus (pollination, auxins, low temperature, etc.). When it is not certain whether fruits without seeds or with empty seeds result from a failure of pollination or fertilization or from abortion of the embryo, these should merely be called *seedless*.

Material and methods.

Twenty-one varieties of apples and of pears were used in these experiments, some of which are listed in Tables II, III and IV.

Two methods of emasculation were used :

(*a*) Petals, stamens and styles were removed with tweezers (method A).

(*b*) The entire upper part of the flowers was cut off with a scalpel (method B). The former flowers were left uncovered ; the latter were covered with paper bags after emasculation (at the balloon stage). Clusters, which were chosen at random all over the branches of trees in the orchard, were thinned to 2–3 flowers, each cluster serving as an experimental unit and at least 25 clusters being used per treatment. The untreated clusters were removed to eliminate the chance that the treated ones had to compete with normal seeded fruits. Records were made of (1) the setting of parthenocarpic fruitlets and (2) the yield of mature fruits. Setting was called positive when a notable swelling of the young fruitlets was observed after 3–4 weeks.

The experiments with Précoce de Trévoux were carried out every year on the same two trees. Other details will be described in the different sections.

EXPERIMENTAL RESULTS.

Vegetative parthenocarpy.

To test vegetative parthenocarpy, prevention of pollination is the critical factor. In all experiments petals, stamens and styles were removed and generally the clusters were enclosed in paper bags (method B). Parthenocarpy without pollination gives an idea of the inherent ability of the plant to set parthenocarpic fruits under naturally occurring conditions.

Owing to the large quantity of experimental results, with 42 varieties several of which were investigated for a period of eight years, only part of the data is given in Tables I and II.

TABLE I.

Number of pear and apple varieties, out of a total of twenty-one of each, (1) setting parthenocarpic fruitlets (i.e. showing notable swelling after 3–4 weeks) and (2) yielding mature fruits.

	Setting parthenocarpic fruitlets			
	Over 20%	10–20%	1–5%	0%
Pear varieties	13	3	5	0
Apple varieties	3	3	6	9
	Yielding mature fruits			
	Over 10%	1–5%	0%	
Pear varieties	4	5	12	
Apple varieties	1	3	17	

It is evident that, in general, pears are more disposed to parthenocarpy than apples. Of the pear varieties all set some parthenocarpic fruitlets, but only twelve of the apples did so. Of the twenty-one apple varieties, seventeen did not mature any parthenocarpic fruits, as against twelve for the same number of pear varieties.

Table II shows that the vegetative parthenocarpy of pears and apples varies from year to year. Most pear and some apple varieties may produce a small number of parthenocarpic fruits once over several seasons. Very few varieties, in these experiments only Précoce de Trévoux, yield an appreciable, though variable, number of parthenocarpic fruits every season. Varieties like Conference presumably take a position between the above-mentioned categories, because they may produce a great many parthenocarpic fruits in one year, but none or only a few in the next.

STIMULATIVE PARTHENOCARPY (AUXIN-INDUCED).

Single auxin treatment.

In attempts to induce parthenocarpy in pears and apples with growth substances two treatments were applied :

(*a*) The flowers were emasculated according to method A and sprayed with 100 p.p.m. β-naphthoxy-α-propionic acid (" NOPA-spray ") with a hand-atomizer. This compound was used because it proved to be effective in the experiments of Osborne and Wain (7) on Pitmaston Duchess, Dr. Jules Guyot, Fertility and Beurré Superfin. The flowers were left uncovered after spraying.

(*b*) The flowers were emasculated according to method B and treated with a lanolin paste containing several growth substances. The mixture of growth substances used was a slightly modified form of that applied by Swarbrick (11) as a spray and consisted of :

TABLE II.

Yearly variability of vegetative parthenocarpy under naturally occurring conditions.

Variety	1948	1949	1950	1951	1952	1953	1954	1955
Beurré d'Anjou	64–38 (39)	37–17 (430)	86–69 (100)	0– 0 (76)*	1– 0 (150)	4– 0 (100)	0– 0 (100)	15– 2 (102)
Clapp's Favourite ..				8– 0 (106)	50–18 (216)	3– 0 (102)	10–10 (100)	
Conference				93– 0 (74)	42–34 (218)	52– 0 (100)	0– 0 (100)	
Précoce de Trévoux ..				53–45 (200)	0– 0 (214)	54–44 (414)	11– 7 (278)	64–37 (198)
Triomphe de Vienne ..						1– 0 (202)		0– 0 (50)
Cox's Orange Pippin ..	72–50 (114)	1– 0 (110)	33– 8 (300)	0– 0 (108)	0– 0 (100)	0– 0 (100)	0– 0 (50)	0– 0 (72)
Gladstone		0– 0 (50)	0– 0 (100)	0– 0 (108)	0– 0 (120)	0– 0 (94)		20– 3 (112)
Goudreinette		0– 0 (204)		0– 0 (110)	0– 0 (100)	0– 0 (100)		
Laxton's Superb†		35– 0 (78)		0– 0 (102)	3– 0 (100)	22– 2 (100)	3– 0 (100)	24– 2 (200)
Winter Gold Pearmain ..				0– 0 (100)	0– 0 (157)	0– 0 (156)	0– 0 (180)	

* First number, per cent. fruits set.
Second number, per cent. fruits harvested.
Between brackets, number of treated flowers.

† In all experiments only the apple Laxton's Superb was used, not the pear of the same name.

5 parts β-indoleacetic acid (instead of β-indolebutyric acid used by Swarbrick),

5 parts α-naphthaleneacetic acid,

5 parts 2:4-dichlorophenoxyacetic acid, and

60 parts β-naphthoxyacetic acid.

This mixture was used as a spray (" Sw. spray " of Table IV) or was converted into a paste (" Sw. paste " of Tables III and IV) by addition of 20 gm. lanolin plus 10 c.c. paraffin oil to 75 mg. of the mixture. The paraffin oil was added to facilitate the application of the paste, but only used in the first two years (1948, 1949) because it turned out to be rather damaging. These flowers were bagged after treatment. The results of the experiments are sumarized in Tables III and IV.

TABLE III.

Pears. Percentage of parthenocarpic fruits set and of harvested fruits.

Treatment	Variety	Year	Number of flowers treated		% fruits set		% fruits harvested	
			C	GR	C	GR	C	GR
NOPA spray	Beurré d'Anjou	1951	76	76	0	24	0	0
,, ,,	,, ,,	1953*	100	100	4	10	0	0
,, ,,	,, ,,	1954*	100	100	0	0	0	0
NOPA spray	Beurré Beucke	1951	100	100	1	6	0	0
Sw. paste	Clapp's Favourite	1951	106	124	8	6	0	0
,, ,,	,, ,,	1952*	150	160	1	0	1	0
,, ,,	,, ,,	1953*	102	102	3	0	0	0
,, ,,	,, ,,	1954	100	100	10	0	10	0
,, ,,	,, ,,	1955	102	102	15	4	2	0
NOPA spray	Conference	1951	74	64	93	98	0	1
Not treated	,,	1952*	216	—	50	—	18	—
NOPA spray	,,	1953*	100	100	52	25	0	0
,, ,,	,,	1954*	100	100	0	0	0	0
Sw. paste	Précoce de Trévoux	1948	39	70	64	51	38	29
,, ,,	,, ,,	1949	430	468	37	56	17	22
NAA paste	,, ,,	1950	100	100	86	87	69	68
Sw. paste	,, ,,	1951	230	246	53	70	45	58
,, ,,	,, ,,	1952*	218	238	42	2	34	1
,, ,,	,, ,,	1953*	414	414	54	27	44	5
,, ,,	,, ,,	1954*	278	278	11	1	7	0
,, ,,	,, ,,	1955	198	198	64	47	37	3
Sw. paste	Triomphe de Vienne	1952*	214	214	0	0	0	0
,, ,,	,, ,,	1953*	202	220	1	0	0	0
,, ,,	,, ,,	1955	50	58	0	0	0	0

GR, treated with growth substances ; C, control.
For composition of auxin preparations, see text.
* In these years night frost occurred after emasculation and treatment of the flowers.

The NOPA spray improved the parthenocarpic fruit set of Beurré d'Anjou and Beurré Beucke to some extent, but proved to have no effect on Conference in 1951 and 1954 and a harmful one in 1953. None of the fruitlets developed into mature fruits but abscissed approximately four weeks after treatment. The application

of Swarbrick paste appeared to be completely ineffective on Triomphe de Vienne and decreased parthenocarpic fruit set and yield of Clapp's Favourite in all years. Its application on Précoce de Trévoux was variable, but in general it did not improve the fruit set.

TABLE IV.

Apples. Percentage of parthenocarpic fruits set and of harvested fruits.

Treatment	Variety	Year	Number of flowers treated		% fruits set		% fruits harvested	
			C	GR	C	GR	C	GR
NOPA spray	Cox's Orange Pippin	1949	110	110	1	35	0	0
Sw. paste	,, ,, ,,	1951	108	104	0	0	0	0
NOPA spray	,, ,, ,,	1951	200	404	1	9	0	0
,, ,,	,, ,, ,,	1954	50	40	0	0	0	0
Sw. paste	,, ,, ,,	1955	72	72	0	5	0	0
NOPA spray	,, ,, ,,	1955	144	142	8	6	1	0
Sw. paste	Gladstone	1951	108	108	0	0	0	0
,, ,,	,,	1955	112	112	20	72	3	0
Sw. spray	Goudreinette	1949	204	292	0	81	0	0
Sw. paste	,,	1950	100	100	0	0	0	0
,, ,,	,,	1951	118	118	0	0	0	0
NOPA spray	Laxton's Superb	1949	78	78	35	81	0	4
,, ,,	,, ,,	1951	102	206	0	32	0	3
,, ,,	,, ,,	1955	200	202	24	33	2	9
,, ,,	Sterreinette	1951	104	200	0	0	0	0
Not treated	Winter Gold Pearmain	1950	50	—	2	—	0	—
Sw. paste	,, ,, ,,	1951	100	100	0	26	0	19

For explanation of terms, see under Table III.

The general conclusion drawn from these data is that only in a few varieties (Laxton's Superb and Winter Gold Pearmain apples) can growth substances increase the yield of mature fruits to any extent. Moreover, Tables III and IV illustrate that not only the vegetative parthenocarpy of most varieties, but also their response to growth substances, may vary from year to year. In these experiments the pears which showed a natural tendency towards parthenocarpy often reacted indifferently or even unfavourably to hormone treatment. On the other hand, this tendency in Laxton's Superb apple was found to be strengthened by a single spray with 100 p.p.m. NOPA.

Repeated auxin treatments.

The results from many experiments showed that flowers that had been sprayed several times did not give a higher yield than those sprayed only once. The data, therefore, are not given in detail. Some varieties of pears reacted to the sprays with an initially increased growth of the fruitlets. Also the setting was sometimes initially increased, e.g. in Beurré d'Anjou. On the other hand Conference blossoms reacted unfavourably to spraying with NOPA. Their setting decreased as the number of sprays increased, as is shown in Table V.

TABLE V.

Parthenocarpic fruits set and yield of mature fruits of some pear and apple varieties after repeated spraying with NOPA (100 p.p.m.).

Number of sprayings	Beurré d'Anjou 1953		Conference 1953		Laxton's Superb 1953		Laxton's Superb 1954	
	% fruits set	% mature fruits	% fruits set	% mature fruits	% fruits set	% mature fruits	% fruits set	% mature fruits
0	4	0	52	0	3	0	22	2
1	10	0	20	0	17	0	15	4
2	38	0	14	0	19	0	12	0
3	—	—	—	—	21	0	19	4
4	48	0	10	0	—	—	32	3
5	—	—	—	—	—	—	29	1
6	48	0	14	0	—	—	24	3
7	—	—	—	—	—	—	19	0
8	55	0	—	—	—	—	19	2

The apples Laxton's Superb and Cox's Orange Pippin were investigated in 1951, 1953 and 1954. The variability in setting of untreated and once or several times sprayed flowers is such that none of the differences can be regarded as significant. The average fruit set of the sprayed flowers was 21 per cent. compared with 22 per cent. of the untreated flowers, while both yielded an average of 2 per cent. mature fruits.

FROST-INDUCED PARTHENOCARPY.

Frost is generally considered to be a factor which induces parthenocarpic fruit setting. Indeed, many instances are known where plants have produced parthenocarpic fruits after exposure to low temperatures (Nitsch, 5). In most of these, however, pollination was not excluded and therefore they are no proof for the theory that frost stimulates parthenocarpic fruit setting. Only in a few experiments was pollination prevented (*Cucurbita*, *Cucumis*, tomato) and in these low temperature certainly stimulated fruit setting (5).

As night frost occurred in several seasons, it has been possible to observe its effect on parthenocarpy. Data are summarized in Table VI and some are also included in Table III.

From Table VI it can be seen that the pear varieties Beurré d'Anjou and Clapp's Favourite, and the apples Cox's Orange Pippin, Goudreinette and Winter Gold Pearmain, which show little or no tendency to produce parthenocarpic fruits, also fail to set parthenocarpically after night frost. This was also illustrated by an experiment with Beurré Beucke, a pear which shows very little tendency to set parthenocarpically under normal conditions. From one tree of this variety all flowers which had not been damaged by frost were removed, leaving some 500 clusters with approximately 1,500 frost-injured (non-emasculated) blossoms. The entire tree yielded only 6 parthenocarpic fruits.

On the other hand, varieties like Précoce de Trévoux and Conference pears and Laxton's Superb apple, which do possess a certain tendency to parthenocarpic

TABLE VI.

Comparison of the parthenocarpic fruit setting in a year without (1951) and one with (1953) night frost (minimum temperature −4° C.) after the emasculation of the flowers.

Variety	1951	1953
Pears :		
Beurré d'Anjou	0–0 (76)*	4–0 (100)
Clapp's Favourite	8–0 (106)	1–1 (150)
Conference	93–0 (74)	52–0 (216)
Précoce de Trévoux	53–45 (230)	54–44 (414)
Apples :		
Cox's Orange Pippin	1–0 (200)	0–0 (100)
Gladstone	0–0 (108)	0–0 (120)
Goudreinette	0–0 (118)	0–0 (100)
Laxton's Superb	0–0 (102)	3–0 (100)
Winter Gold Pearmain	0–0 (100)	0–0 (157)

* First number, % fruits set.
Second number, % fruits harvested.
Between brackets, number of treated flowers.

fruit setting, may set irrespective of night frost. Précoce de Trévoux especially demonstrates that frost has little connection with parthenocarpy. It is either ineffective or it is harmful to parthenocarpic fruit setting and yield. This variety may give a heavy crop consisting entirely of parthenocarpic fruits, irrespective of whether frost occurred before or during the blossom period, or not at all.

In 1951 an experiment was carried out with flowers of Beurré d'Anjou and Conference that had been injured by a frost occurring before flowering. A number of these flowers and of non-frozen flowers were emasculated (method A) and sprayed with 100 p.p.m. NOPA, the controls being sprayed with water (Table VII).

TABLE VII.

Effect of frost damage and spraying with 100 p.p.m. β-naphthoxy-α-propionic acid on parthenocarpic fruit set of emasculated pear flowers.

Condition and treatment of flowers	Beurré d'Anjou			Conference		
	Number of flowers	% fruits set	% mature fruits	Number of flowers	% fruits set	% mature fruits
Not frozen { water	76	0	0	74	93	0
Not frozen { 100 p.p.m. NOPA	76	18	0	64	98	1
Frozen { water	76	0	0	88	18	0
Frozen { 100 p.p.m. NOPA	76	8	0	92	24	1

The data recorded in Table VII show that there was no setting when flowers of Beurré d'Anjou had been sprayed with water. Both frozen and non-frozen flowers set after treatment with NOPA, the latter more freely than the former. In neither

were mature fruits harvested. With Conference the non-frozen blossoms set about four times as well as the frozen ones, irrespective of whether they were sprayed with water or NOPA. The non-frozen and frozen blossoms which were sprayed with hormone yielded one parthenocarpic fruit each.

In 1952 and 1953 insect-pollinated blossoms which already showed some swelling were treated with Swarbrick paste a few days after the flowers had become frozen during a severe night frost. No setting at all of either treated or untreated flowers (100 per treatment) occurred in both years on Triomphe de Vienne, Beurré Superfin and Clapp's Favourite pears or on Goudreinette, Winter Gold Pearmain, Cox's Orange Pippin, Laxton's Superb and Gladstone apples.

DISCUSSION.

The phenomenon of parthenocarpic fruit setting is important both from a theoretical and from a practical point of view. Before one can determine whether and, if so, when to apply auxins for parthenocarpic fruit setting, it is necessary to know which factors affect fruit growth in general and parthenocarpic fruit growth in particular. The experiments mentioned are part of a series designed to gain some insight into both problems, especially for Dutch varieties of apples and pears under Dutch climatic conditions.

From the observed data the following general conclusions became evident :

(*a*) In general, parthenocarpic setting is better in pears than in apples.

(*b*) Parthenocarpic fruit setting shows wide varietal differences in various years. This means that some varieties have a certain inherent ability for parthenocarpic fruit setting, others have not. Very few varieties produce parthenocarpic fruits every year, others never. In between are those varieties which only occasionally set parthenocarpic fruits.

(*c*) The yield of the parthenocarpic varieties varies greatly in different years (in Précoce de Trévoux from 7–69 per cent.).

(*d*) Only in some varieties (e.g. Winter Gold Pearmain, Laxton's Superb) can auxins induce a slightly higher production of parthenocarpic fruits than that of the controls. The setting of the fruitlets is in general somewhat better, undoubtedly as a result of delayed abscission.

(*e*) In these experiments frost was never found to favour parthenocarpic fruit setting.

The high variability in vegetative parthenocarpy of the different varieties indicates that several factors (internal and external) are influencing parthenocarpy.

With regard to the degree of inherent ability to set parthenocarpic fruits, it is suggested by the authors that this is related to the longevity of the ovules. It is highly probable that fruit growth, whether parthenocarpic or normal, is initiated by the ovules. Hence a greater longevity of the ovules, which would lead to a greater production of auxin or to a greater enzymatic conversion of a precursor to auxin, would increase the probability of parthenocarpic fruit setting.

Schanderl (9) found that the non-fertilized ovules of pears live several weeks longer than those of apples. This coincides with the fact that pears in general have a greater tendency for parthenocarpic fruit setting and are less dependent on the development of good seeds for normal fruit growth than are apples. These

observations more or less substantiate the importance of ovule longevity for parthenocarpic growth. Again, the findings of Crane and Marks (2), who obtained crossings between pear and apple only when using parthenocarpic pears as the mother plant, point in this direction. It seems reasonable to assume that it is only in parthenocarpic varieties that the ovules remain alive long enough to give the pollen tube the opportunity to reach the egg cell. In this connection it is noteworthy that in tomatoes small but not degenerated ovules are present in the mature parthenocarpic fruits.

Vegetative parthenocarpy is largely dependent on environmental factors. This shows the necessity for more fundamental research in this field. This line has already been followed by some investigators (Luckwill, Wain) with tomatoes. Similar research is also necessary with pomaceous fruits. Empirical research or observations have nothing more to contribute to the better understanding of the phenomenon parthenocarpy.

SUMMARY.

1. During 1948–55, twenty-one varieties each of pears and apples were investigated for their ability to set parthenocarpic fruits, with and without auxin application.

2. Setting of small parthenocarpic fruits, as shown by swelling three to four weeks after emasculation, occurred in all twenty-one pear varieties and in twelve apple varieties.

3. Of all the pear and apple varieties tried in these experiments, mature parthenocarpic fruits were produced occasionally and to a varying extent by nine varieties of pears (Précoce de Trévoux, Pitmaston Duchess, Conference, Contesse de Paris and five others) and by five of apples (Gladstone, Laxton's Superb, Winter Gold Pearmain, Yellow Transparent and Ellison's Orange).

4. Only Précoce de Trévoux produced parthenocarpic fruits every year, but to a variable extent (7–69 per cent.).

5. Growth substances occasionally increased fruit set, but seldom the number of mature parthenocarpic fruits (Laxton's Superb).

6. Frost never induced parthenocarpy.

7. Parthenocarpic fruit setting is, apart from large varietal differences, subject to differences in environmental conditions. This necessitates more fundamental research.

8. It is suggested that the longevity of the ovules is an important factor governing parthenocarpic fruit growth.

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THE EFFECT OF CERTAIN METEOROLOGICAL CONDITIONS ON STURMER APPLE YIELD

By H. S. ROBERTS

Applied Mathematics Laboratory, Department of Scientific and Industrial Research, New Zealand

MANURIAL trials in progress on different varieties of apple trees in the Nelson district, New Zealand, were first laid down in the year 1930 and have been described and analysed by Tiller *et al.* (in the press). Although records are available for several varieties of apple trees, the present paper deals only with those for the Sturmer variety. All trees used in the experiment were planted in 1916, the area being managed as a commercial orchard until 1930 when it was acquired for experimental work. For the years 1930 and 1931, uniformity trials were conducted, the manurial applications being withheld until 1932. Complete yield records have been kept since 1930, but the yields analysed in this paper are for the period 1933–53.

A climatological station was established at the orchard in 1930 and meteorological records have been kept since the experiment began.

A question of some importance was whether or not there was any relationship between the yield and the various meteorological factors, and the problem as set out here attempts to find the most important of these factors and the critical times at which these effects take place.

METHOD OF STATISTICAL EXAMINATION OF RESULTS.

The meteorological factors considered were arbitrarily selected by the author and officers of the Fruit Research Division of the New Zealand Department of Scientific and Industrial Research. It was assumed that, with the fruit being picked in April, the most important period would be from July to December of the year prior to harvest, this being the period when the climate was likely to have its greatest effect on such factors as fruit setting, flowering, cell division, and major increase in cell-size. The meteorological factors for this period are denoted by the subscript " x-1 ". It was suggested, however, that the conditions of the second year before that of harvesting might have some effect ; where these have been considered they have been denoted by the subscript " x-2 ". The rainfall in the two months immediately prior to harvest was also included, this period being denoted by the subscript " x ". Altogether a total of twenty-one meteorological factors was considered ; these are listed below, together with the corresponding symbols :

Number of days of frost in June	$June_{x-2}$
Number of days of frost in July	J_{x-1}, J_{x-2}
Number of days of frost in August	A_{x-1}, A_{x-2}
Extreme minimum temperature in October (*a*)	t_{x-1}, t_{x-2}
Number of days of rain in October	R_{x-1}, R_{x-2}

Total rainfall October to December	OD_{x-1}, OD_{x-2}
Total rainfall July to December	JD_{x-1}, JD_{x-2}
Total air temperature July to December (*b*)	U_{x-1}, U_{x-2}
Total average temperature July to December (*c*)	V_{x-1}, V_{x-2}
Total extreme maximum temperature July to December (*d*)	W_{x-1}, W_{x-2}
Total rainfall in February	F_x
Total rainfall in March	M_x

(*a*) Extreme minimum temperature as measured 4 ft. above ground (screen frost). At this height it approximates more closely to the temperature of the fruit than would a reading taken at ground level.

(*b*) Air temperature as given by the dry bulb. The figures given in the records are the average readings for the month, these averages being simply summed over the stated period.

(*c*) Daily maximum temperatures averaged for the month and daily minima similarly averaged. Also recorded was the average of these two figures, this final average being summed from July to December.

(*d*) Extreme maximum temperature for each month summed from July to December.

All records were made at 9 a.m. New Zealand mean time.

In addition to the meteorological factors the effect of the previous season's yield (Y_{x-1}), that of two seasons previous (Y_{x-2}), and the general overall trend due to ageing from year to year (X) were also considered. There was thus a total of twenty-four factors. With the equipment available, viz. Powers-Samas punched cards and electric hand-calculators, it was deemed impossible to handle all factors simultaneously ; hence the number of units was reduced by arbitrary assembly of factors into small groups. It was also decided that it was not possible to work with more than eight factors at a time. Factors were first tested for significance ; those found to be non-significant were dropped and others were then included to make up a new eight for testing. This procedure was continued until all twenty-four factors had been tested.

The test procedure was as follows : To test, for example, the effect of total rainfall from July to December (JD_{x-1}) of the year immediately preceding the crop in conjunction with seven other factors, let V_2 be the residual variance when JD_{x-1} is included and V_1 the residual variance when it is excluded, N the number of years for which observations have been taken, and p the number of factors being considered in the test. Then the test function (Wilks, 1932 ; Whittle, 1953) $(N-p) \log_e \frac{V_1}{V_2}$ is distributed approximately as χ^2 with one degree of freedom. In this example, where JD_{x-1} is tested in conjunction with seven other factors, N—p would equal 11 (19—8).

The Sturmer experiment consisted of 120 trees, divided into 20 plots each of six trees. The plots were grouped in four different blocks, five different treatments being randomly applied within each block. The treatments, apart from control, were N, P, NP, NPK where

N = an annual application of nitrogen as sulphate of ammonia at the rate of 2 lb. per tree (2 cwt. 44 lb. per acre).

P = an annual application of phosphate as superphosphate (44/46 per cent. P_2O_5) at the rate of 4 lb. per tree (4 cwt. 88 lb. per acre).

TABLE I.

Levels of χ^2.

Manurial treatment	Y_{x-1}	Y_{x-2}	X	June $_{x-2}$	J_{x-1}	J_{x-2}	A_{x-1}	A_{x-2}	t_{x-1}	t_{x-2}	R_{x-1}	R_{x-2}
Control		6·64**	3·00			0·03				0·22		0·07
P		9·77**	8·62**			3·94*				0·46		0·08
N		4·04*	13·03***			7·69**				0·27		0·28
NP		4·57*	6·72**			7·35**				2·92		0·57
NPK	0·15	2·85	4·69*	0·93	0·31	10·46**	0·08	0·01	0·02	2·96	0·30	
	OD_{x-1}	OD_{x-2}	JD_{x-1}	JD_{x-2}	U_{x-1}	U_{x-2}	V_{x-1}	V_{x-2}	W_{x-1}	W_{x-2}	F_x	M_x
Control							4·51*					
P	0·67						5·02*					
N	0·12						2·43					
NP	0·48						6·31*					
NPK	1·19	0·07	0·86	0·16	0·62	0·00	2·38	1·08	0·18	0·00	1·81	1·27

Levels of significance for χ^2 with 1 degree of freedom :

5% = 3·84*
1% = 6·63**
0·1% = 10·83***

K=an annual application of potash as either sulphate or muriate of potash at the rate of 1 lb. per tree (1 cwt. 22 lb. per acre).

The yield figures as shown in the graphs (Figs. 1–5) and in Table II are the mean plot yields, i.e. the figure for each year represents a total yield from six trees. Treatments were first applied in 1932 and the first yield records after application were available in 1933 ; but the first yields that could be used were those for 1935, because some meteorological factors were obtained by extrapolating back two years. For computational purposes 1935 has been taken as the second year (i.e. for 1935, x=2).

RESULTS.

Of the twenty-four factors tested, only four were found to have a significant effect, viz. the yield two seasons previous (Y_{x-2}), the average temperature summed from July to December of the previous year (V_{x-1}), the number of days of frost in the July twenty-one months before harvest (J_{x-2}), and the general ageing of the tree (X). Of these, only two were meteorological. The four factors did not significantly affect all the treated plots in the same manner, as can be seen from an examination of Table I, where the χ^2 values and significance levels of the factors are set out. Only those values which were significant have been given. The first yields tested were those of the NPK treatment, and after an examination of the significance of these effects it was decided, again on account of the heavy computational work involved, to make a selection of these factors for use with the other treatments.

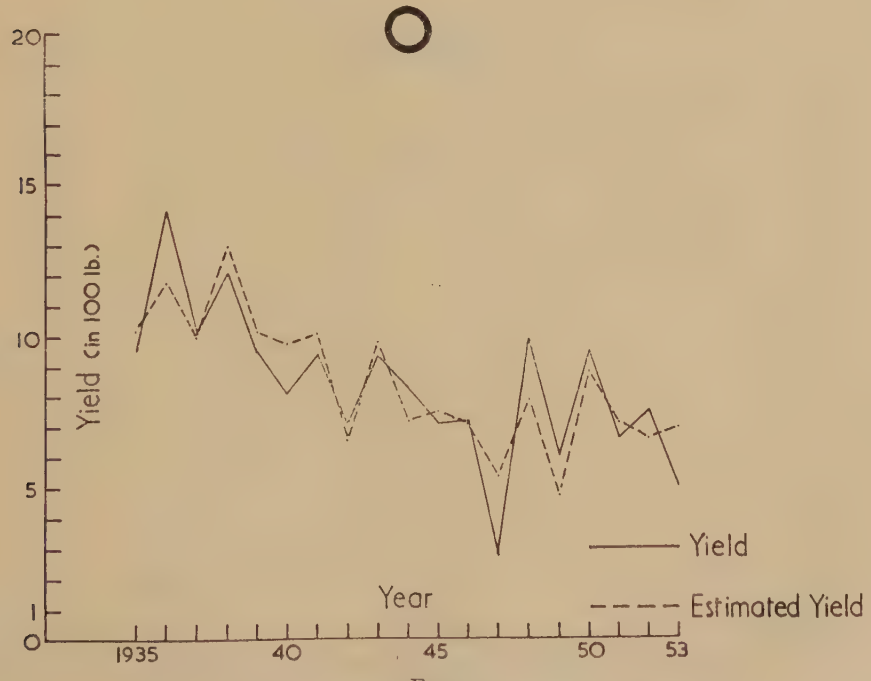

FIG. 1.

Actual and estimated yields ; control plots.

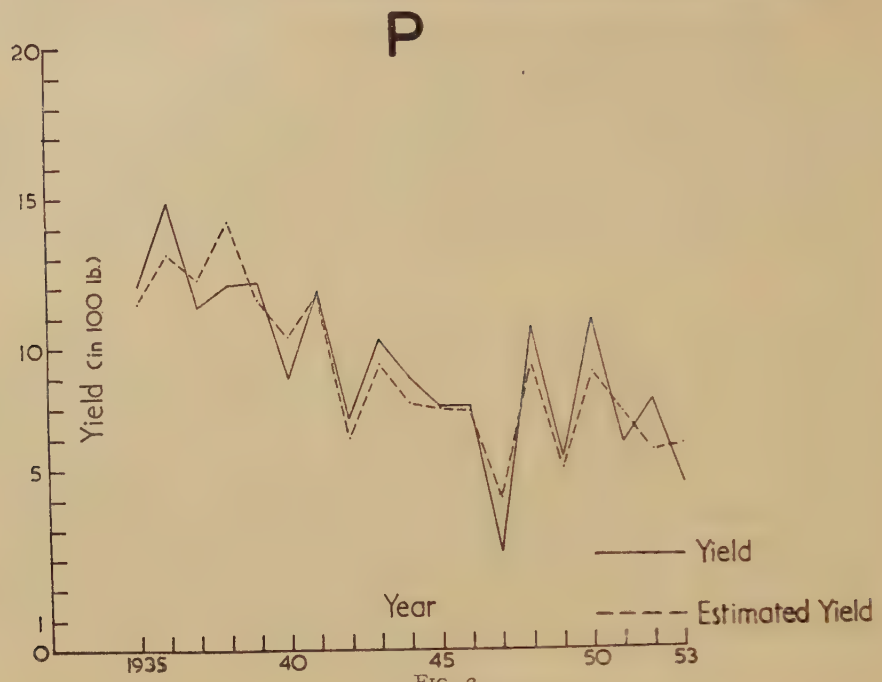

FIG. 2.
As in Fig. 1 ; P plots.

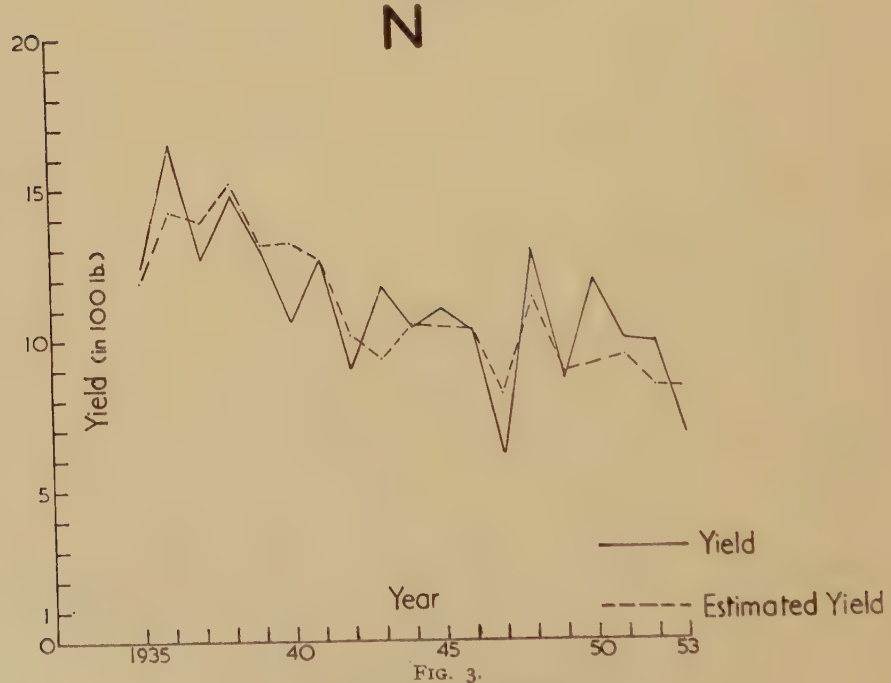

FIG. 3.
As in Fig. 1 ; N plots.

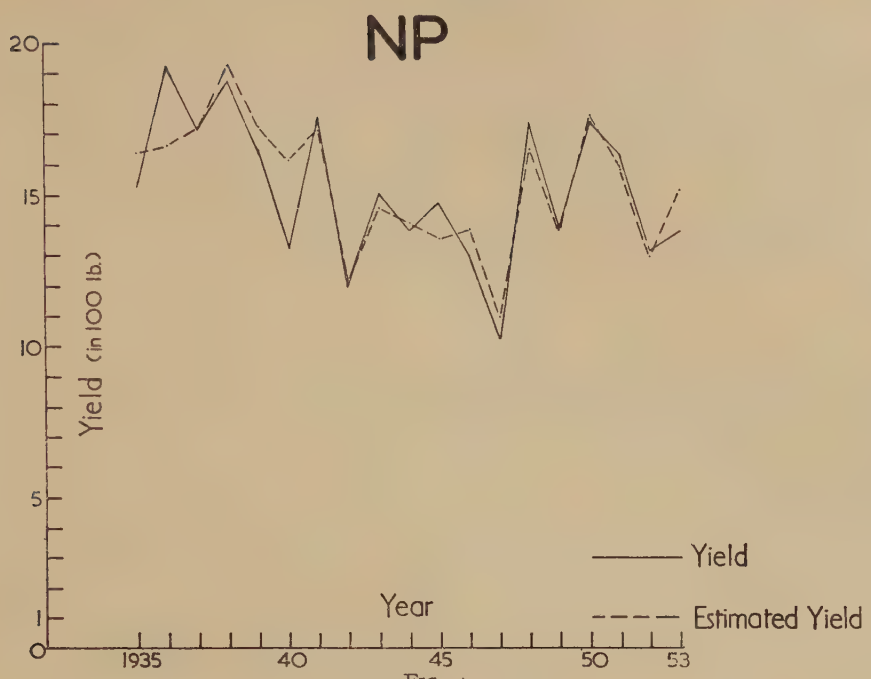

FIG. 4.
As in Fig. 1 ; NP plots.

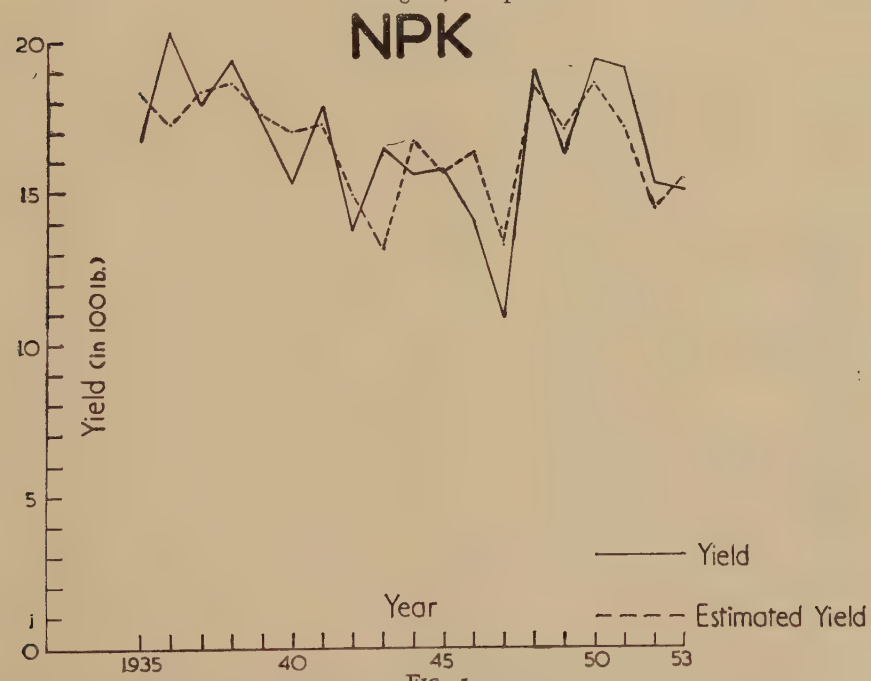

FIG. 5.
As in Fig. 1 ; NPK plots.

These significant factors, together with the means in each case, have been fitted to the yield graphs and are shown in Figs. 1–5. The equations for the fitted graphs are as follows :

Fig. 1 (Control), $Y = -81{\cdot}87 - 0{\cdot}13X \qquad + 0{\cdot}50Y_{x-2} + 0{\cdot}28V_{x-1}$

Fig. 2 (P), $Y = -62{\cdot}50 - 0{\cdot}24X - 0{\cdot}20J_{x-2} + 0{\cdot}42Y_{x-2} + 0{\cdot}23V_{x-1}$

Fig. 3 (N), $Y = \ 12{\cdot}98 - 0{\cdot}30X - 0{\cdot}29J_{x-2} + 0{\cdot}31Y_{x-2}$

Fig. 4 (NP), $Y = -67{\cdot}58 - 0{\cdot}18X - 0{\cdot}29J_{x-2} + 0{\cdot}31Y_{x-2} + 0{\cdot}26V_{x-1}$

Fig. 5 (NPK), $Y = \ 21{\cdot}62 - 0{\cdot}17X - 0{\cdot}42J_{x-2}$

CONCLUSIONS.

It must be emphasized that the following conclusions apply only to the Sturmer variety. As can be seen from the graphs, the Sturmer is not a pronounced biennial bearer. With the more strongly biennial bearers, such as Cox's Orange Pippin and Dunn's Favourite, these meteorological factors may not have so noticeable an effect.

An interesting result is the significant effect of the number of frost days in July, twenty-one months previous to harvesting, on the treated plots (J_{x-2} in Table I). On the untreated plots the value of χ^2 was only 0·03. The effect is significant with the P treatment, but much more so with the treatments which include N. In each case the correlation between the yield and these frost days is negative, i.e. the greater the number of frost days in July, the less the yield twenty-one months later. In Table II are given the relevant yield and frost figures for the NPK treatment.

TABLE II.

Yield (lb.) of NPK plots in relation to number of frost days in the July of two years previously.

Year	Yield	No. of frost days in July	Year
1935	1,675	7	1933
1936	2,038	9	1934
1937	1,793	6	1935
1938	1,942	5	1936
1939	1,737	7	1937
1940	1,542	8	1938
1941	1,792	7	1939
1942	1,381	12	1940
1943	1,653	16	1941
1944	1,561	7	1942
1945	1,580	9	1943
1946	1,406	7	1944
1947	1,094	14	1945
1948	1,913	1	1946
1949	1,637	4	1947
1950	1,948	0	1948
1951	1,916	3	1949
1952	1,537	9	1950
1953	1,510	6	1951

The raw correlation coefficient of these two (where the correlation is computed by comparing, for example, the 1935 yield with the 1933 frost) without taking into

account any other effects is −0·61. This indicates that a high frost figure corresponds to a low yield, although the 1943 yield is an exception. It was felt, before the analysis, that the most important frost effect was likely to be that of screen frost in October (t_{x-1}, t_{x-2}), but the χ^2 value of this factor for NPK for the year previous to the yield was only 0·02 and for the two years previous was 2·96. With the other treatments it was also non-significant.

Another point of interest is that, generally, a yield in any given year is not significantly correlated with the following year's yield, but is significantly correlated with the yield two years later, the correlation being positive (Y_{x-2} in Table I). There was a slight effect on the NPK treatment by this factor ($\chi^2 = 2·85$) but not enough to give significance.

It seems that the ageing effect on a tree (X in Table I) is much more marked with the treated trees than with the untreated, the χ^2 value for the control plot being only 3·00. However, it is shown by Tiller *et al.* (in the press) that the NPK yield, for example, is nearly twice that of the control plot, so that any drop in yield caused by the age of the tree is not likely to affect seriously the benefits of greater yield derived from the application of this fertilizer. It is almost impossible to extrapolate to future yields from the available data in order to determine whether the untreated trees are ever likely to give greater yields than the treated trees. But since these long-term experiments are still being continued it is possible that an answer to the question may be given by future data.

Although it may appear from a visual examination of the graphs that the decline due to ageing is as great with the control plot as with the others, nevertheless the statistical tests show that with the former the effect is not significant. It is not justifiable to compare visually one graph with another since the ageing trend is obscured by other factors. For example, with the NP treatment (Fig. 4), the decline with time seems relatively steep from 1935 to 1947, but from 1935 to 1953 the overall decline seems to be much less. It is thus difficult to estimate the ageing effect without taking into account the other significant factors.

Of the temperature effects considered, the most critical seems to be that of the average temperature from July to December of the year previous to the yield (V_{x-1} in Table I). The χ^2 value for the N treatment was 2·43 and for the NPK 2·38, the correlations between yield and temperature being positive for each treatment. The indications are that for an increase in yield it is more important to have generally warm weather in the months before yield, rather than a small amount of extremely hot weather. Since the χ^2 values with the NPK plot for U_{x-1}, U_{x-2}, W_{x-1}, and W_{x-2} were 0·62, 0·00, 0·18 and 0·00 respectively, it did not seem worth while to test these effects with the other treatments.

A final point worth noting is that no significant rainfall effects were found. This may have been due either to failure to select the critical rainfall period, or to there being no critical rainfall period at this orchard. During the years under consideration there was no month in which some rainfall was not recorded, and it seems likely that the soil retains enough moisture to supply the needs of the trees through dry periods.

SUMMARY.

The effects of twenty-one meteorological factors on the yield of Sturmer apple trees were examined. Of these only two were found to be significant: (1) total

average temperature from July to December in the year immediately preceding harvest, and (2) the number of days of frost in July twenty-one months previous to harvest, this effect increasing with the increasing level of fertilization.

The effects of two other factors were also found to be significant : (1) the yield two years previously (pointing to a biennial bearing tendency), and (2) a general ageing trend.

ACKNOWLEDGMENTS.

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THE ASSESSMENT OF YIELD IN CANNING-PEA VARIETIES IN SCOTLAND

By C. NORTH, L. H. FRITH and H. TAYLOR
Scottish Horticultural Research Institute, Invergowrie, by Dundee

BETWEEN 1944 and 1954 the acreage of peas grown in Scotland for canning rose from 300 to 2,900 (Dept. Agric. Scot., 1956) and, among Scottish horticultural crops, peas are now second in importance only to raspberries. Because there was no information on the performance of different pea varieties in Scotland, the choice of varieties for this rapidly expanding industry was of necessity determined largely by the experience of growers in England. Trials were begun at Invergowrie with the object of finding which of the most widely grown varieties give the highest yields under Scottish conditions.

Preliminary trials made in 1952 and 1953 gave very little useful information because of bird damage and the difficulty of judging when to harvest the crop. In 1954 these setbacks were largely overcome ; a satisfactory trial procedure was evolved, and used with slight modifications during the following three years. However, after six years' experience with trials at the Scottish Horticultural Research Institute, peas are still considered the most time-consuming and expensive vegetable crop to test.

Method.

All the trials were at Invergowrie where the climate and soil are typical of the greater part of the Scottish pea-growing area (mainly the counties of Angus and Perthshire). No fertilizers or bulky organic manures were added to the land used for the trials as it was known to be in good heart and to have a high phosphate content.

The sowing rates were adjusted to conform approximately to general commercial practice (2 cwt. per acre of seed of 80 per cent. germination), but allowance was made for differences in seed weight in order to obtain similar plant population densities of each variety. Germination percentages needed for these adjustments were obtained from tests on 600 seeds of each variety sown in soil and kept in a glasshouse at 50–60° F. In 1956, counts showed that the calculated sowing rates had given an intra-row plant spacing ranging from 2·3 to 2·9 inches. This spacing is similar to that used by Sayre, Tapley and Barton (1953) for trials at Geneva, New York, and ranges from the optimum to slightly wider than the optimum spacing of seed found by Reynolds (1950) for the varieties Harrison's Glory and Mansholts G.E.K. in Lincolnshire.

Seed was treated with a proprietary dust containing thiram and sown by hand in drills 1–2 in. deep. Each trial consisted of a randomized block layout with six replications. Seven varieties were tested, six of which had already been grown commercially in Scotland. The seventh, Wando, was included because it had given

high yields in preliminary tests. Each plot consisted of nine rows 33 ft. long. In 1954 the rows were spaced 9 in. apart but in subsequent years 12 in. apart. In 1956 and 1957 single rows of Atle wheat were sown round each plot 1 ft. from the outside row of peas ; this prevented plants from different plots becoming entangled with one another.

The crop was kept free from weeds by hand hoeing. No chemicals were used for weed control as they frequently have a selective effect on the growth of some pea varieties. Attempts were made to decrease damage by rooks and pigeons by scaring the birds with acetylene-operated bangers and by shooting.

When most of the pods contained swelling peas the state of maturity of the crop was assessed every two or three days by the " Alcohol Insoluble Solids " (A.I.S.) test devised by Kertesz (1930) and also with a texturemeter, a hand-operated instrument designed by Cristel (1938). Whenever these tests were made, the weight of peas per pod was also recorded. Each variety was harvested as near as possible to the " Practical Canning Stage " (P.C.S.) which, for the purpose of these trials, was equated with an A.I.S. content of 13·5 per cent. for all varieties. At this stage the plants give the highest yield of peas in good condition for canning. The crop was cut with a sickle, the pods picked from the haulm by hand and shelled in a podding machine. The peas were weighed immediately after shelling.

Results.

Table I shows the yields of peas and haulm. Sometimes it was impossible to harvest the crop when the A.I.S. content was exactly 13·5 per cent., so that not all the yields shown in this table are from crops harvested at the P.C.S. Unfortunately this difficulty was not foreseen. Consequently the trials were not designed in a manner that would allow for the adjustment of yields to P.C.S. and the subsequent statistical analysis for significant differences between adjusted yields. Nevertheless it is possible, with the available data, to calculate corrections which may be applied to offset the discrepancies in stages of maturity at harvest. The figures in Table II are based on regressions of measurements of A.I.S. contents and yields of peas per pod on times of sampling for a range of maturity from 8 to 15 per cent. A.I.S. ; they are the means for all varieties. The information on some varieties is incomplete

Table I.

Yields of peas and haulm.

Variety	Shelled peas (cwt./acre)				Ratio of haulm to shelled peas		
	1954	1955	1956	1957	1955	1956	1957
Monarch Canner	—	57·7	78·9	51·9	3·7	4·3	3·9
Lincoln	67·0	56·7	67·5	68·5	3·8	5·6	3·5
Witham Wonder	53·3	52·4	60·4	50·4	4·5	4·7	4·1
Kelvedon Wonder	61·8	52·0	64·5	43·2	4·3	4·7	4·7
Wando	—	55·7	66·8	30·7	3·6	4·7	6·8
Canner's Perfection	74·5	50·0	57·2	51·0	4·6	5·0	4·1
Gregory's Surprise	57·8	52·0	47·6	33·2	4·1	5·4	5·7
Sig. Diff. (P=0·05) ..	12·3	2·3	7·8	5·6			

and the figures are therefore approximations. However, it is felt that they give a reasonable measurement of rate of maturation because there is a fair degree of uniformity in the calculated figures for different varieties within any one year.

Mean air temperatures and rainfall recorded at the Institute's main meteorological site during the ripening period (10 days before harvesting the earliest-maturing variety until the day of harvesting the latest-maturing variety) are given in Table II, together with data on maturing of the peas and on increase in yield. It is seen that temperature during the ripening period had a considerable influence on the daily increment of A.I.S. but no well-defined relationship between temperature and daily increase in yield is apparent. There is no evidence that the rainfall during the ripening period had influenced the rate of ripening.

The figures in Table II were used to calculate the adjusted yields and times taken to reach P.C.S. shown in Table III.

Table II.

Rate of ripening of pea crop in relation to climatic conditions.

Year	Increase in % A.I.S. per day	Increase in yield per day*	Mean air temperature during ripening period (° F.)	Rainfall during ripening period (in.)
1954	0·30	3·6	55·6	1·86
1955	1·30	5·2	61·2	—
1956	0·34	3·8	56·5	5·17
1957	0·59	5·4	58·5	—
Mean, 1954–7	0·63	4·5		

* Expressed as percentage of yield when A.I.S. content is 13·5 per cent.

Table III.

Adjusted yields and times taken to reach Practical Canning Stage (A.I.S. content 13·5 per cent.).

Variety (in order of time taken to reach P.C.S.)	Yield of shelled peas (cwt./acre) at P.C.S.					No. of days from sowing to P.C.S.				
	Mean 1955–7	1954	1955	1956	1957	Mean 1955–7	1954	1955	1956	1957
Kelvedon Wonder	50	54	47	65	39	95	120	92	102	91
Gregory's Surprise	42	45	48	43	35	95	106	93	99	93
Monarch Canner ..	62	—	58	75	53	100	—	98	106	97
Wando	49	—	50	64	34	100	—	97	105	98
Witham Wonder ..	54	58	52	60	51	101	117	97	109	98
Canner's Perfection	46	89	45	51	42	103	123	98	112	103
Lincoln	59	72	45	65	66	104	120	98	111	105
Date sown ..							14th Apr.	19th Apr.	22nd Apr.	23rd Apr.

In America, Boswell (1927, 1929) found that the time taken for garden peas to reach certain stages of maturity could be related to the summation of day degrees above 40° F. Recently Hänsel (1950) has confirmed this finding in Germany. Summation of day degrees above a threshold temperature, the so-called " accumulated heat units " or " accumulated temperatures ", has been recommended by several authors as a basis for forecasting the harvest date of pea crops, especially in America. Accumulated heat units for the periods from sowing to P.C.S. are given in Table IV for the trials in 1955, 1956 and 1957 ; full meteorological data for 1954 are not available. The range of variation in heat units required by any one variety during the period was 80–270, which corresponds to 6–20 days' growth.

TABLE IV.

Accumulated heat units for period from sowing to P.C.S.

Variety (in order of A.H.U. requirement)	Mean	1955	1956	1957
Kelvedon Wonder	1,230	1,170	1,360	1,150
Gregory's Surprise	1,260	1,170	1,340	1,260
Monarch Canner	1,340	1,270	1,430	1,340
Wando	1,350	1,250	1,410	1,390
Witham Wonder	1,360	1,250	1,480	1,360
Canner's Perfection	1,380	1,260	1,530	1,340
Lincoln	1,410	1,260	1,510	1,440

Texturemeter readings were generally lower and more variable for peas shelled by machine than for those shelled by hand. The relationship between texturemeter readings and A.I.S. content of pea samples shown in Fig. 1 is therefore given only for measurements on hand-shelled peas. Each point represents the mean of three estimations made by each method used to measure the degree of maturity. The regression line is calculated to fit the results of all four years of records. Correlation coefficients between texturemeter readings and A.I.S. contents for individual years from 1954–7 inclusive were $+0{\cdot}908$, $+0{\cdot}857$, $+0{\cdot}961$ and $+0{\cdot}662$ respectively.

DISCUSSION AND CONCLUSIONS.

To obtain a valid assessment of yield, different varieties of canning peas must be compared at equivalent stages of maturity. From the consumer's point of view, tasting tests are the best means of judging maturity but such tests are difficult to operate and maturity is usually assessed by some objective method. The A.I.S. test, generally accepted as the most accurate of these methods, is tedious, and a quicker mechanical method of assessment would be preferable. Of the instruments available for this purpose the tenderometer is universally claimed to be the most accurate ; it is, however, large and expensive. The texturemeter, which is a small portable and comparatively inexpensive instrument, could be of great practical value if it were sufficiently precise. Torfason *et al.* (1956) consider that it differs little in precision from the tenderometer, and Nilsson *et al.* (1953) have used it exclusively for the assessment of the maturity of canning-pea varieties in trials in Sweden.

Our comparisons between texturemeter readings and A.I.S. contents suggest

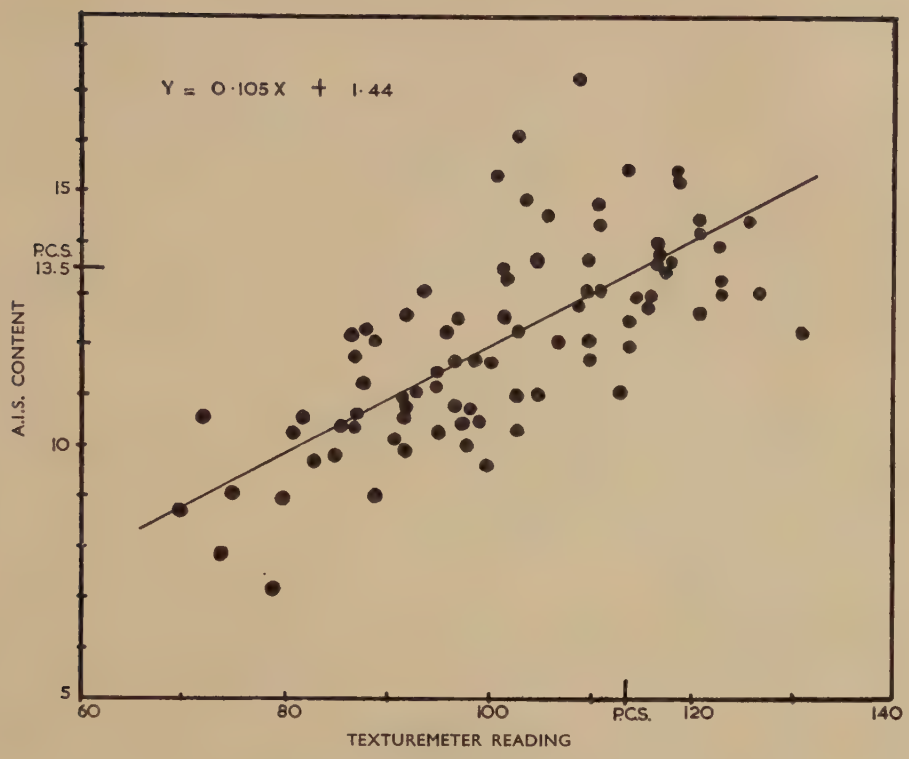

Fig. 1.
Relationship between texturemeter reading and A.I.S. content.

that the texturemeter is not a sufficiently accurate instrument to determine the harvest date of canning-pea crops under Scottish conditions. We found correlation coefficients between A.I.S. content and texturemeter reading which, except in 1956, were less than the mean (+0·9533) recorded by Torfason *et al.* (1956) for the period 1951–3 inclusive. Moreover, our calculations showed that changes in texturemeter reading indicated significant ($P < 0·05$) changes in A.I.S. content only if they exceeded 30 points. This margin of error is equivalent to about 12 days' growth in the field under average Scottish summer conditions and is much greater than the 5 points margin, corresponding to less than one day's growth under Swedish conditions, found by Nilsson *et al.* (1953). Nevertheless, the texturemeter may be a useful adjunct to A.I.S. tests for preliminary determination of the maturity of peas. The crop is unlikely to have reached an A.I.S. content of 13·5 per cent. in Scotland if the texturemeter reading is below 94.

Except in 1955 the daily increment in A.I.S. of raw peas (Table II) was lower than that found by Adam (1957) for crops grown at Chipping Campden in England. He noted seasonal average rates of 0·65–1·2 per cent. per day for a number of varieties of canning peas during 1954–7 inclusive. His calculations, however, are based on a range of A.I.S. of 10–16 per cent., whereas those given in Table II are for a range of approximately 8–15 per cent. Since the rate of increase in A.I.S. accelerates as ripening progresses, one would expect the Invergowrie values to be

slightly less than Adam's because they relate to crops at an earlier mean stage of maturity. Nevertheless, with the exception of the 1955 figures, the Invergowrie values are all so much lower than Adam's that the difference cannot be fully explained on this basis. It seems reasonable to conclude that in 1954, 1956 and 1957, peas matured more slowly at Invergowrie than in central England. It is probable that the rate of maturation in the main canning-pea area of Scotland may be slower than in many parts of England, except during exceptionally warm weather such as was experienced in 1955.

The range of accumulated heat units required by a variety to reach P.C.S. varied so widely from year to year as to suggest that A.H.U. are not likely to be of any general value for forecasting the date of harvest in Scotland. However, they may be of some slight value for forecasting harvest dates in areas where pea crops have not been grown before and for which temperature figures are available. A comparison of the Invergowrie figures for accumulated heat units with those found by Adam for the same varieties in England (unpublished data) shows that peas probably require 50–100 less A.H.U. to reach P.C.S. in Scotland than in England. Whatever the reason for this difference, the practical implication is that due allowance should be made for such a difference if English A.H.U. figures are used for forecasting the time of harvest in Scotland.

A detailed discussion of the behaviour of the individual varieties is of local interest only and therefore outside the scope of this paper, but some aspects of the yield comparisons are of general interest and therefore pertinent here. A comparison of yield is useful only if it is made between varieties which mature at approximately the same time. The varieties grown in the trials fall into three maturation groups : early, Gregory's Surprise and Kelvedon Wonder ; midseason, Witham Wonder, Monarch Canner and Wando ; maincrop, Lincoln and Canner's Perfection. Of the early-maturing varieties, Kelvedon Wonder seems to have yielded higher than Gregory's Surprise in all years except 1955. The inferior performance of Surprise may not, however, have been so well defined as indicated in Table III because, unlike most other varieties, the average A.I.S. content of a crop of this variety at P.C.S. is probably about 15·5 (Adam) instead of 13·5 per cent. The yield figures for Surprise may thus relate to crops in a less mature state than those for Kelvedon Wonder. If the yields of Surprise had been adjusted to an A.I.S. content of 15·5 they would, except in 1955, still have been slightly lower than those of Kelvedon Wonder and the P.C.S. would in general have been reached some three to five days later. Thus Kelvedon Wonder probably matures slightly earlier than Gregory's Surprise and gives better yields.

A knowledge of the haulm-producing capacity may be of value because those varieties which give a higher ratio of haulm weight to pea weight are more expensive to cart from the field after cutting. Varietal differences are rather inconsistent but a general appraisal of the figures in Table I shows that Monarch Canner consistently gave a relatively low yield of straw to peas.

SUMMARY.

1. Yield trials of seven varieties of canning peas are described.

2. Stage of maturity of the crops was measured by the Alcohol Insoluble Contents of the peas and also with a texturemeter.

3. The value of the texturemeter as an instrument for determining the Practical Canning Stage of pea crops is discussed.

4. The results of the trial suggest that canning peas may ripen more slowly in Scotland than in many parts of England.

ACKNOWLEDGMENTS.

We wish to express our thanks to Mr. W. B. Adam for his advice on the technique employed in these trials and for permission to use unpublished information ; also to Mr. D. M. Leighton for passing on to us the results of preliminary trials in canning peas made at Invergowrie before 1954.

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A THREE-YEAR COMPARISON OF CAPTAN AND LIME SULPHUR AS POST-BLOSSOM FUNGICIDES ON COX'S ORANGE PIPPIN APPLES

By R. J. W. BYRDE, G. M. CLARKE and C. W. HARPER
Long Ashton Research Station, University of Bristol

For the past thirty years lime sulphur has been the standard fungicide used in most parts of the British Isles against apple scab, caused by *Venturia inaequalis* (Cooke) Wint. There has been increasing awareness, however, that it is liable to cause injury to varieties other than those generally recognized as "sulphur-shy" and in particular to Cox's Orange Pippin; moreover, it is possible that such injury is accentuated by the highly surface-active modern wetting agents. The first introduction of organic fungicides in the 1930's was followed in the post-war years by an intensive search for another material which would be equally effective against scab, but without the phytotoxicity of lime sulphur towards Cox (Marsh, 1947).

The fungicide now known as captan, which was first introduced by Kittleson (1952) in the U.S.A., showed promise in preliminary laboratory tests at Long Ashton against spores of *Sclerotinia laxa* Aderh. & Ruhl. (Byrde, 1952), and proved outstanding in pilot-scale field trials against apple scab in this country, both at Long Ashton (Marsh, 1955) and at East Malling (Moore and Kirby, 1952).

The material was subsequently made available on a commercial basis and has been the subject of a number of reports in the scientific and technical press (e.g. Bush, 1956). Broadly speaking, captan has given excellent control of apple scab in all parts of this country and there has been considerable evidence of increased crops resulting from its use. On the other hand, it soon became evident that apple mildew, caused by *Podosphaera leucotricha* (Ell. and Everh.) Salm. and normally held in check by routine lime sulphur spraying, was not controlled by captan, and the increased incidence of this disease has led to the abandonment of captan spraying in some orchards in eastern England.

After four years of small-scale testing, a three-year field trial was started at Long Ashton in 1954 with the object of comparing captan and lime sulphur as post-blossom fungicides under West Country conditions, lime sulphur being used as the pre-blossom fungicide. The experiment was laid out according to statistical principles of design in order that the results could be appraised as fully as possible. The detailed results for the individual years 1954–6 have already been published (Byrde *et al.*, 1955, 1956, 1957); in 1957 a captan programme was applied to the entire orchard, in order to obtain further information on the effects of differential treatments in the previous year. This paper presents the results obtained in 1957 together with an analysis of the experiment as a whole.

Materials and methods.

Fungicides.

The spray materials were formulated as follows :

Lime sulphur, as a commercial concentrate diluted as required to 2, 1½, 1 or ¾ per cent.

Captan (N-trichloromethylthiocyclohex-4-ene-1:2-dicarboxyimide, previously known as N-trichloromethylthio-tetrahydrophthalimide), as an aqueous suspension of a commercial wettable powder (50 per cent. captan) and used at 1½ lb. per 100 gal.

The sprays were applied at approximately 250 gal./acre by a mobile spraying machine using two twin- or triple-nozzle brooms with $\frac{4}{64}$-in. disc apertures, giving outputs of 3–3½ or 6 gallons respectively per minute.

Fungicide spray applications in 1954–6 comprised one or two pre-blossom applications of lime sulphur (1–2 per cent.) on all plots. Three or four post-blossom sprays were applied, comparing lime sulphur (0·75 per cent.) with captan (0·075 per cent.). In 1957 captan (0·075 per cent.) was used throughout the whole experimental area, both pre- and post-blossom. Full details of spray applications have been quoted elsewhere (Byrde *et al.*, 1955, 1956, 1957, 1958).

Layout.

The trial was carried out on a 3-acre grass orchard of bush trees of the variety Cox's Orange Pippin, with the varieties Laxton's Superb and Winston as pollinators. The orchard was initially laid out in 1947–8 as a trial of tree spacing and planting systems, and the pomological aspects of this long-term trial are described in this number (Hobbis and Catlow, 1958).

The orchard contained 22 rows, running east to west, of the variety Cox's Orange Pippin interspersed with Winston as permanent bush trees on M.II rootstock, at a 24-ft. square plant. Four such rows (large capitals only) are shown in Fig. 1. At the ends and middle point of each row were trees of Laxton's Superb (S), also on

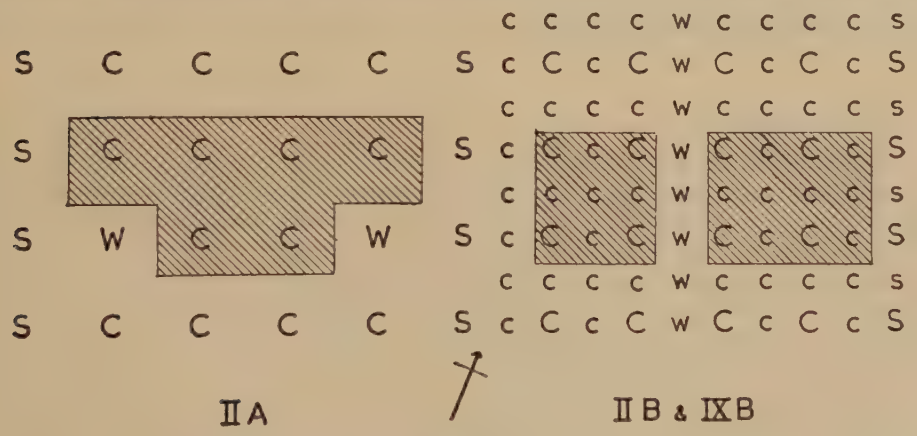

Fig. 1.

Layout of a single plot. The shaded areas denote trees recorded.
C = Cox. W = Winston. S = Laxton's Superb.
Large letters represent M.II rootstock.
Small letters represent M.IX rootstock.

M.II. The east side had fillers of Cox, Winston and Superb on M.IX (small capitals), to give a 12 ft. square plant. The west and east sides represent planting systems A and B respectively of Hobbis and Catlow (1958). Each experimental plot consisted of four rows on the west and eight rows on the east side. Only the Cox's which are shaded in Fig. 1 were recorded for each plot. There were thus double guard rows, parallel to the prevailing (westerly) wind, between each recorded plot but guards at the extreme ends (north and south) of the plantation had to be dispensed with.

The trees on M.II and M.IX (C and c respectively) in planting system B were recorded separately; these will be referred to as planting systems II B and IX B though, in fact, they are merely constituent portions of Hobbis and Catlow's planting system B. The trees in planting system A will be referred to as II A.

The six available plots formed three randomized blocks, each of two plots: treatments were allocated to plots in 1954–6 as indicated in Table I.

TABLE I.

Allocation of post-blossom fungicide treatment to experimental plots, 1954–7.

Block	Plot North-South	Post-blossom fungicide			
		1954	1955	1956	1957
1	N	LS	LS	LS	C
	S	C	C	C	C
2	N	LS	C	C	C
	S	C	LS	LS	C
3	N	C	LS	C	C
	S	LS	C	LS	C

LS = lime sulphur; C = captan.

During 1954–6 lime sulphur was used throughout pre-blossom; in 1957 captan was used throughout pre-blossom.

Methods of assessment.

Apple mildew. An estimate of overwintered (primary) mildew infection on blossom trusses was made by sampling five trusses, chosen at random (Byrde *et al.*, 1956) from each of six trees per experimental plot in each planting system. These were classed as infected (if any mildew observed) or healthy. In 1957, mildew which had overwintered on vegetative shoots of the previous season's growth was estimated by a similar method. Mildew infection of the current season's growth, i.e. secondary infection, was estimated in late summer by an examination of ten shoots per tree; each was recorded as infected or healthy.

Apple scab on fruit. The total fruit from each recorded plot was bulked in three batches corresponding to the three planting systems, and random samples of fifty to sixty fruits were taken from orchard boxes by the method of Pearce (1947). Intensity of scabbing was assessed by Tehon and Stout's method, as amplified by Marsh (1947). This involves visual comparison of each fruit with diagrams showing a known percentage area scabbed.

Fruit russet was estimated, as a percentage area of the total fruit surface, by visual comparison with models showing 10 per cent. and 25 per cent. of the area affected. Three categories were distinguished : less than 10 per cent. ; 10 to 25 per cent. ; more than 25 per cent.

Other records. Fruit grading for size and colour was carried out on a commercial machine. Crop weight was recorded for each tree in pounds.

Statistical treatment of results.

As has been pointed out, only six experimental plots could be obtained on each planting system. Analyses of variance and significance tests could therefore reveal only large differences, but smaller ones might be of economic interest. Emphasis was thus placed on estimation of the main effect of each spray treatment in a season, and of the residual or carry-over effect of each treatment into the following season. Main effects were estimated for the seasons 1954, 1955, 1956 and residuals for 1955, 1956, 1957. It has been assumed that in 1955 and 1956, the records of crop, scab, mildew and russet could be explained by the expression: grand mean + block effect + main effect + residual effect + random error. The figures quoted below for mean yield, disease incidence, etc., are (*a*) (for main effects) the estimates of grand mean + main effect, and (*b*) (for residuals) the estimates of grand mean + residual effect. These can be interpreted as (*a*) mean values eliminating the previous season's treatments, and (*b*) mean values of residuals, eliminating the current season's treatments. In 1954 only main effects were present, and in 1957 only residuals. Throughout, the assumption has been made that residual effects last no longer than one season ; on the evidence of the results analysed in this trial this assumption appears reasonable.

Notes on weather.

Detailed rainfall data for seasons 1954–7 are published in progress reports (Byrde *et al.*, 1955, 1956, 1957, 1958). The period included a dry summer (1955) and two wet summers (1954 and 1956) ; 1957 started dry but became wetter. In each of the four years, the month of April was dry, often with cold easterly winds. This necessitated some caution in application of pre-blossom lime sulphur sprays and accounts for the decreased concentrations used in some years.

RESULTS.

Apple mildew.

Overwintering mildew on blossom trusses was at a low level throughout the experiment. Taking all planting systems as a whole, and ignoring residual effects, the mean percentages of infected trusses in the spring following treatment were, for

Table II.

Mean percentage of vegetative shoots of previous season's growth showing mildew infection ; 30th May, 1957.

1956 post-blossom fungicide	Planting system		
	IIA	IIB	IXB
Lime sulphur	7 } **	4	5 } **
Captan	19 } **	15	23 } **

** Diff. sig. at 1 per cent. level.

lime sulphur and captan respectively: in 1955, 0·0 and 0·7; in 1956, 0·0 and 0·4; in 1957, 0·4 and 0·4.

Overwintering mildew on vegetative shoots was also recorded in 1957, reflecting the 1956 treatments, as shown in Table II.

Summaries of main and residual treatment effects on secondary mildew infection on shoots of the current season's growth for the period 1954–7 are presented in Tables III and IV. Although the pattern of results is somewhat variable, the superiority of lime sulphur in checking the disease is clearly indicated. In 1954 and 1956 the main effects were significant in all three planting systems. In most instances differences due to residual effects were small by comparison with those due to main effects, but it is noteworthy that eight out of the nine values quoted are in favour of lime sulphur, suggesting the existence of a long-term effect.

TABLE III.

Secondary mildew infection in late summer ; main treatment effects.

Planting system	Post-blossom fungicide	Mean % current season's shoots showing mildew infection		
		1954	1955	1956
IIA	Lime sulphur	3·3 } ***	27·6	43·5 } *
	Captan	23·0 }	46·1	78·5 }
IIB	Lime sulphur	2·7 } ***	20·6	24·5 } **
	Captan	30·3 }	42·4	75·2 }
IXB	Lime sulphur	4·3 } ***	29·5	22·2 } *
	Captan	18·0 }	49·2	80·2 }

* Diff. sig. at 5 per cent. level.
** Diff. sig. at 1 per cent. level.
*** Diff. sig. at 0·1 per cent. level.

TABLE IV.

Secondary mildew infection in late summer ; residual treatment effects.

Planting system	Post-blossom fungicide used in previous year	Mean % current season's shoots showing mildew infection		
		1955	1956	1957
IIA	Lime sulphur	33·6	57·5	74·7
	Captan	40·1	64·5	88·3
IIB	Lime sulphur	24·4	51·5	68·3
	Captan	38·6	48·2	85·0
IXB	Lime sulphur	26·7	49·7	66·0
	Captan	52·0	52·7	85·7

Apple scab.

Incidence on fruit was almost zero, apart from an occasional infected fruit from the most northerly plot. Under these circumstances it was not considered that a

statistical analysis would serve any useful purpose. The data are summarized in Table V, ignoring residual effects ; in 1957 the mean values were 0·00 per cent. throughout.

Table V.

Apple scab ; main treatment effects.

Planting system	Post-blossom fungicide	Mean % fruit area scabbed		
		1954	1955	1956
IIA	Lime sulphur	0·08	0·04	0·04
	Captan	0·01	0·01	0·01
IIB	Lime sulphur	0·07	0·02	0·02
	Captan	0·00	0·00	0·01
IXB	Lime sulphur	0·02	0·01	0·00
	Captan	0·00	0·00	0·00

Fruit russet.

The data are summarized in Table VI which shows the percentage of fruit with less than 10 per cent. surface area deeply russeted. Clearly, the disorder was most widespread in 1954, and in that year there was a highly significant treatment effect in favour of captan. In 1956 there was a significant effect on planting system IX B only, and it would appear that M.IX rootstock may confer greater susceptibility to russeting than M.II. As might be expected, residual effects were very small, and are not quoted.

Table VI.

Fruit russet ; main treatment effects.

Planting system	Post-blossom fungicide	Mean % fruits with less than 10% surface russeted		
		1954	1955	1956
IIA	Lime sulphur	65·0 } ***	98·4	92·8
	Captan	91·7 }	98·9	89·5
IIB	Lime sulphur	60·7 } ***	95·5	87·9
	Captan	94·7 }	99·8	93·4
IXB	Lime sulphur	39·7 } ***	89·1	87·2 } **
	Captan	93·3 }	95·9	97·2 }

** Diff. sig. at 1 per cent. level.
*** Diff. sig. at 0·1 per cent. level.

Crop weight.

Results are summarized in Table VII for main effects and in Table VIII for residual effects. It will be seen that, for planting system IX B, there are no significant differences between treatments in any season. For planting system II A, however, captan gave a significantly greater crop than lime sulphur in 1955 and 1956, and the residual effects of the previous season's sprays were in favour of captan in each of the three years 1955–7 ; this effect attained statistical significance in 1957.

For planting system II B, main and residual effects were generally in favour of captan, but a rather high variability in this planting system prevented any of the differences from attaining statistical significance.

TABLE VII.

Crop weight ; main effects.

Planting system	Post-blossom fungicide	Mean crop per tree (lb.)			Total
		1954	1955	1956	
IIA	Lime sulphur ..	35·8	22·9 *	117·1 *	175·8
	Captan	51·3	52·5	173·5	277·3
IIB	Lime sulphur ..	40·0	38·2	97·8	176·0
	Captan	28·7	67·5	128·6	224·8
IXB	Lime sulphur ..	32·3	24·8	36·1	93·2
	Captan	32·5	31·2	47·3	111·0

* Diff. sig. at 5 per cent. level.

TABLE VIII.

Crop weight ; residual effects.

Planting system	Post-blossom fungicide in previous year	Mean crop per tree (lb.)			Total
		1955	1956	1957	
IIA	Lime sulphur ..	33·6	136·0	136·0 *	305·6
	Captan	41·8	154·5	162·8	359·1
IIB	Lime sulphur ..	50·2	103·2	149·0	302·4
	Captan	55·5	123·2	156·3	335·0
IXB	Lime sulphur ..	28·0	44·7	77·2	149·9
	Captan	28·0	38·6	61·3	127·9

* Diff. sig. at 5 per cent. level.

TABLE IX.

Commercial grading ; 1954.

Planting system	Post-blossom fungicide	% total crop in "Fancy" grade	% total crop in "Fancy" grade and over 2¼ in. diam.
IIA	Lime sulphur ..	38·7	24·5
	Captan	48·9	35·9
IIB	Lime sulphur ..	38·4 *	22·4
	Captan	51·8	42·2
IXB	Lime sulphur ..	41·4	30·6 *
	Captan	54·8	45·8

* Diff. sig. at 5 per cent. level.

Commercial fruit grading.

Data for individual seasons have been presented in progress reports (Byrde *et al.*, 1955, 1956, 1957, 1958). On the basis of percentage total crop in the "Fancy" grade, or percentage total crop in this grade and larger than 2¼ in. diameter, there were no significant treatment differences other than in 1954, for which the results are summarized in Table IX. All six comparisons are in favour of captan, although only two of them attain statistical significance. Residuals were negligible in all seasons, as might be expected.

DISCUSSION.

It will be clear from the layout of the experiment that it lacked some desirable statistical qualities : replication was of a low order and the estimates of seasonal main effects and residuals were not independent. The straightforward methods of analysis of variance could not therefore be applied to all the data. However, essential principles of design were present : there was adequate guarding between recorded trees, there was initial randomization of treatments, there was blocking to allow for the slope of the site, and all sampling methods were random.

Despite the statistical limitations of the layout, it has been possible to examine not only treatment differences in the current season, but also the presence of residual effects arising from the treatments of the previous season. Such residuals were apparent in the data for apple mildew and crop weight. It seems that the residual effect on mildew is a measure of the amount of overwintering inoculum, and the data obtained on vegetative shoots in the spring of 1957 suggest that these, rather than blossom trusses, carried the principal inoculum of the disease in this trial. With regard to the residual effect on crop weight, pomological studies on a single block in the trial in 1956 showed that a greater proportion of fruit bud developed into blossom trusses on the plot which had received captan during the previous year (Luckwill, 1957). This may well have been a factor in other instances where a significant residual effect on crop was observed. Suggestions have appeared in the technical press that captan applied in one season tends to reduce the crop in the following : the evidence from these data is to the contrary for M.II rootstock, but inconclusive for M.IX.

Little of economic importance arises from data presented on scab incidence, owing to its very low level, though it is noteworthy that only 5–7 fungicide applications were made during the season. The data on commercial grading, taken as a whole, show little treatment difference, but they indicate that the increased crop following the use of captan is not necessarily associated with a reduction in fruit size. Cox spot and *Botrytis* and *Rhizopus* fruit rots were encountered during the trial, and observations suggested that the first-named might be more severe on captan-treated plots.

It is clear that the incidence of apple mildew is the limiting factor in the use of captan. In this trial, lime sulphur was used pre-blossom in 1954–6, and this may have tended to check mildew, though other work has shown that any such check is likely to be small (Burchill, 1958). On M.II rootstock, the high incidence of mildew on captan plots was far outweighed economically by the increased crop (mean of II A and II B, 25 lb. per tree representing a 42 per cent. increase) in the current season, and the expected increase (14 lb. per tree representing 14 per cent.) in the following

season. On M.IX, treatment differences were not significant in any season ; on the other hand, in two out of the four seasons, the use of captan significantly decreased fruit russet on this rootstock. Broadly speaking, therefore, the benefits of captan seem to have been greater to trees on M.II rootstock than on M.IX.

The steady increase in mildew incidence on the plot receiving captan post-blossom in all four seasons is well shown by the mean percentages, for all planting systems, of shoots showing secondary infection : 1954, 14·5 per cent. ; 1955, 45·5 per cent. ; 1956, 76·1 per cent. ; 1957, 82·8 per cent. Although such secondary infections on the current season's growth are often confined to the leaves and thus do not overwinter, such a build-up of infection is likely to lead eventually to crop reduction through destruction of potential fruit buds. Before this stage is reached, it would clearly be desirable to reduce the mildew level either with a mildew-specific fungicide (such as karathane) or by reverting to an all-sulphur programme for a season.

Finally, it must be emphasized that the above conclusions refer only to a single trial in one orchard in four particular seasons, variable as they were, and are not necessarily valid for other parts of the country, or even for other seasons. In the east of England, for instance, the spread of mildew is often so rapid as to make captan spraying uneconomic (Bush, 1956). In practice, it seems that the commercial use of captan will be governed largely by the relative magnitude, on an economic basis, of its effects on crop and mildew.

SUMMARY.

1. Captan (0·075 per cent.) and lime sulphur (0·75 per cent.) were compared as post-blossom fungicides, following lime sulphur pre-blossom, on the apple variety Cox's Orange Pippin in 1954–6. A randomized block layout was used in which treatments were re-allocated each year.

2. The incidence of apple scab, caused by *Venturia inaequalis*, was very low throughout the trial. Apple mildew, caused by *Podosphaera leucotricha*, was more severe on plots receiving captan.

3. The use of captan on trees on M.II rootstock was followed by a mean increase in crop weight of 25 lb. per tree, representing a 42 per cent. increase. With trees on M.IX, there was little effect on crop weight, but fruit russeting was largely prevented.

4. Critical examination of the data, together with those obtained after a uniform spray treatment in 1957, indicated a residual effect of the previous season's sprays on apple mildew incidence and, on M.II rootstock only, on crop weight ; both tended to be higher following captan.

5. It is concluded that a major consideration in the commercial use of captan is its relative economic effects on mildew and yield in a given orchard.

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THE PERFORMANCE OF THREE VARIETIES OF DESSERT APPLE TREES AT LONG ASHTON UNDER DIFFERENT SYSTEMS OF PLANTING, SPACING AND SHAPING

By E. W. HOBBIS and E. CATLOW
Long Ashton Research Station, University of Bristol

In setting out a new plantation the commercial fruitgrower has the choice of extensive or intensive systems or of a compromise between the two. Where trees are planted well apart and trained as bushes or standards, the arrangement would be considered extensive ; the term intensive would be applied where, in order to gain early returns, trees are planted as dwarf-pyramids at the rate of 1,000-2,000 plants per acre ; the third method employs dwarf early-fruiting trees as "fillers" between the more vigorous permanent trees to hasten crop returns, the intention being to remove the fillers once the more permanent trees need the space.

The performance of apple trees at various spacings in the Midlands and South-West was reviewed in 1944 (2) and 1945 (3). The post-war planting boom followed shortly afterwards and in order to obtain more precise information on the potential value of different planting systems a field trial was planned at Long Ashton. In the winter of 1947-48 an area of approximately $3\frac{3}{4}$ acres was planted to dessert apple trees to be grown under four different systems of planting, spacing and shaping. A progress report on this experiment was made after 5 years (5) and an account was also given at that time of the performance of the cordons (4). The following report concerns the performance of the trees under each planting system over a period of ten years.

In 1953 it was possible to sponsor the planting at the N.A.A.S. Experimental Horticulture Station, Luddington, Warwickshire, of apple trees under each system dealt with in this report and including also a plot of dwarf bushes, but this experimental planting is too young, as yet, to contribute usefully to the information included in this paper.

EXPERIMENTAL PROCEDURE.

Planting.

Soil and site.

The field sloped gently to the south, with greater soil depth at the lower end. Drainage was generally good but previous experience in growing vegetables on this area had shown the fertility to vary considerably across the field as well as with the slope. The soil is derived from Keuper Marl with some overwash from the limestone and a considerable amount of stone is present both in surface and subsoil.

Layout.

The four systems were :

A : bush trees on M.II rootstock at 24 ft. square, i.e. 75 trees per acre, without interplants.

B : bush trees as in A, with the addition of dwarf fillers on M.IX rootstock interplanted at 12 ft. apart, i.e. 75 permanent trees plus 227 filler trees per acre—302 trees in all.

C : single cordons on M.II rootstock, planted 8 ft. × 3 ft., i.e. 1,815 trees per acre.

D : dwarf pyramids on M.II rootstock, planted 8 ft. × 4 ft., i.e. 1,361 trees per acre.

These four systems were not replicated but each was planted in a single strip running N. to S. with the slope of the land : A and B covered about 1½ acres each and C and D approximately a third of an acre each.

Varieties and rootstocks.

Materials for the trial were raised at Long Ashton and planted out in 1948 as maiden trees from which well feathered trees were selected for cordons and dwarf pyramids in particular.

The greatest number of trees, for each system, were of Cox's Orange Pippin. In systems A and B, Laxton's Superb and Winston were included as pollinators, the Superbs forming buffer rows on the flanks and between the two systems. The planting was so arranged that five trees of Cox and one of Winston formed a unit for trees on M.II. In the cordons and dwarf pyramids Winston was used as a 1 in 4 pollinator in the row. M.II rootstock was used for all but the bush filler trees which were worked on M.IX to encourage early cropping in view of their expected short tenure (see Fig. 1 of Byrde *et al.*, p. 245 of this number).

Comparative planting costs.

Table I sets out the comparative costs per acre of planting trees under the four systems, at the cost of labour and materials ruling in 1948. To these costs should be added expenses incurred during the first season after planting, viz. for operations such as mulching, manuring, cultivation and spraying which are inseparable from the post-planting treatment. Since no staking was necessary for the dwarf pyramids the labour of planting was considerably less per tree than under the other three systems. No figure has been included for cost of land or for perimeter fencing.

Table I.

Planting costs per acre (£) in 1948.

System	Bush trees	Bush trees + fillers	Oblique cordons	Dwarf pyramids
Trees (at 5s. each)	19	75	454	340
Materials	6	24	142	0
Labour	12	17	100	22
Total	37	116	696	362

MANAGEMENT.

A. Bush trees at 24 ft. square.

Previous experience at Long Ashton had shown that Cox on M.II can fill out a spacing of about 24 ft. within 20 years of planting ; Laxton's Superb can occupy this spacing in about 15 years ; and it was thought that Winston, which in growth is roughly comparable to Worcester Pearmain, would be more than amply spaced at 24 ft. In these circumstances, therefore, it seemed that an arrangement at 24 ft. square of bush trees on M.II, in the three varieties, would be most suitable.

Undercropping was avoided, to give the trees every opportunity to develop rapidly and fill out the space in the shortest possible time.

Pruning and shaping. During the first five or six years these operations were aimed at producing trees of delayed-open-centre form, in which a central stem 4-5 ft. high carries branches from 2 ft. 6 in. upwards and is terminated by a more or less open-centre head. The main branches were spaced in a roughly spiral fashion up the central stem and were not developed as widely spaced opposed pairs as is sometimes done.

The variety Cox developed shapely, well-balanced, spreading trees and fruiting laterals were easy to induce ; Laxton's Superb trees grew rapidly, sometimes too rapidly, and were markedly affected in shape and balance by wind ; the variety Winston grew stiffly upright and not until the tenth year did cropping cause noticeable branch spread.

From the first, tipping of leaders was relatively lightly done, the central leader being pruned a little harder than those of the limb system to reduce dominance of the central shoot. When the leaders had grown out of easy reach, tipping was discontinued, a stage reached progressively over several years, generally from the fifth year onwards. This policy seems to have been justified since over-stiffening of the branches was avoided and cropping opened out the branch system and, with Cox and Superb, created a spreading type of tree. The encouragement of replacement branches from the upper sides of the branch system provided a means of replacing the original branches where these had been pulled outwards and downwards enough to hinder cultivations.

The treatment of laterals throughout the ten years followed the general principles of renewal pruning. By the end of the fifth year most trees had become well furnished with one-, two- and three-year-old laterals, with natural spurring increasing each year.

B. Bush trees with fillers.

Pruning and shaping of the bush trees were exactly as described in A but the filler trees were treated differently. Branching was started at 2 ft. from the ground and tipping was only hard enough to stiffen the few initial branches and to encourage sufficient new growth. As trees on M.IX cannot be trained readily with a delayed-open-centre form, each cropping bent the branches outwards from an early age.

Trees on M.IX were planted as fillers in expectation of their quick development and fruiting during a short period, say about 10 years, in which they could be allowed to remain without detriment to the more permanent ones. This surmise proved to be correct. Some crowding became apparent towards the end of the eighth year and in the ninth season overcrowding was general, once the crop had pulled down the

branches. It was necessary during this period to provide passage-way for machinery without damage to the permanent trees and this necessitated "cutting up" two-thirds of the fillers. However, the filler in the centre of each square of trees on M.II was pruned as little as possible, in the hope that it would remain when grubbing of the rest of the trees on M.IX became necessary. The tenth year provided heavy crops on both bush and filler trees. Growth continued to be good and by mid-season it was impossible to take tractor machinery through the plantation. Grass cutting was continued until the end of August; after this a narrow path was cut between the tree rows, but this became increasingly difficult to maintain as the trees became weighted down by crop. Immediately after picking the crop, all fillers, other than those in the middle of the square, were grubbed, leaving only 75 fillers per acre in place of the original 227.

Soil management. Systems A and B were treated alike throughout. For the first four years, summer cultivations with spring-tined cultivators and harrows maintained a clean, arable surface until the end of August when cultivations ceased and weeds were allowed to grow, the surface being undisturbed until the following spring. The winter weed cover checked erosion, which had at times been quite marked on this field, and eased the work of pruning and spraying under winter conditions.

In the fifth year the plantation was sown in August to Kent Wild White clover at 3 lb. per acre which gave a good overall cover. The clover was quickly invaded by indigenous grasses and the proportion of clover varied each season. In the tenth year the general appearance in summer was that of a fairly good overall clover sward.

Spraying. From 1948 to 1953 inclusive, spraying followed the normal winter and summer programmes, which included lime sulphur for scab control. In the four seasons 1954-57 the bush trees were used for a comparison of captan and lime sulphur for the control of scab. An account of this trial appears on page 244 (1).

In 1954/55 and 1955/56 winter washing with tar oil was replaced by spring spraying at the green-cluster stage, with BHC/DDT, but tar oil was applied again in 1956/57.

Manuring. All trees in systems A and B were mulched with F.Y.M. in the spring following planting and fertilizers at the rate of 2 cwt. superphosphate and 1 cwt. sulphate of potash per acre were applied annually in the years 1948-1951, inclusive. These rates were raised to 3 cwt. and 2 cwt. respectively in 1952 (fifth year) in preparation for sowing a sward and were afterwards reduced to 2 and 1 cwt. respectively. In 1956 and 1957 both phosphate and potash were applied as part of a complete granular fertilizer.

No nitrogen was applied to the trees until their fifth year in the field when, in the spring prior to seeding down to a clover sward in the summer, 3 cwt. Nitro-chalk was applied per acre. In the sixth year the nitrogen dressing was raised to the equivalent of 4 cwt. sulphate of ammonia per acre and maintained at that level up to and including 1957.

Symptoms of magnesium deficiency became apparent in 1951 and two foliar sprays of magnesium sulphate were applied in 1952 and subsequent years. The sprays were supplemented in 1953 and 1955 by a general dressing of 2 cwt. magnesium sulphate per acre. In 1956 and 1957 foliar sprays only were given.

C. Cordons.

The cordons of Cox's Orange Pippin and Winston on M.II rootstock were planted at the same time as the bush trees, in rows 8 ft. apart and 3 ft. apart in the rows.

Each tree was planted against a cane secured at an angle of 45° to a substantial wire fence. There was a sharp difference in soil fertility half way along the rows and this materially affected the growth and performance of the cordons. The variety Winston occurred as every fourth tree in the rows as a pollinator.

Pruning and shaping. In the hope of obtaining heavy crops within a few years of planting, the cordons were not pruned on the orthodox spurring methods that restrict cropping to a narrow band along each cordon stem. In order to increase cropping, a limited number of the lateral shoots growing outwards and sideways were allowed to develop as small branches and, to speed up flower bud development, they were tied down on a curve during the summer months. The retention of a proportion of the laterals in this way was practised from the maiden stage, when a few of the feather shoots were left untouched at the first pruning. Laterals not so treated were either summer-pruned, or spurred during winter pruning. Over-vigorous shoots were cut clean away. The cordons at the lower (South) end of the plot grew vigorously and, as they had reached the top of the fence in the fourth year, they were lowered to an angle of about 30° to the ground, to allow of greater length. The remainder of the cordons were lowered in the sixth year.

The trees grew well every year and the retention and tying down of some laterals each summer was easy to accomplish; the danger from about the sixth year onwards was in tying down too many, with resultant over-shading of the fruit and poor colour. By cutting away the oldest laterals, reducing the number of shoots tied in and resorting to a little summer pruning, this problem was solved and crops were not only heavy but reasonably well coloured. These cordons are now very different in appearance from the familiar, orthodox, close-pruned version and most of the flower buds are carried on fruiting laterals left in for a term of years, until replaced by younger shoots, which are then similarly treated.

The very variable soil conditions of the site and the resultant variation in growth from very vigorous to only moderate necessitated harder pruning on many of the cordons in order to maintain new shoot growth each year; this was often too short and the shoots too few in number to warrant tying-in. A detailed account of the pruning and development of these cordons has already appeared (4).

Soil management. Cultivations given to the cordons were similar throughout to those given to the bush trees, except that a 2 ft. wide ribbon of soil was kept hoed along the rows for two years after grassing down the alleyways. Grassing down was carried out in August of the fifth year, using Kent Wild White clover at the rate of 3 lb. per acre.

Manuring. Except for mulching along the rows for the first two years after planting and for five years on the poorer section, the cordons were manured in the same way as the bush trees.

Spraying. The cordons received the same basic spray programme as the bush trees until 1954, in which year and for the following seasons captan was applied throughout for scab control. In 1957 spraying against scab was carried out with lime sulphur.

D. Dwarf pyramids.

The trees were planted alongside and in line with the cordons, in rows 8 ft. apart with trees 4 ft. apart in the rows. This distance keyed in very well with the width of

the cordon rows and seemed an appropriate spacing for the use of small power tools for cultivation and automatic spraying, whilst retaining a high tree population.

The varieties Cox and Winston were planted in the ratio of 3 : 1, as with the cordons, and all trees were worked on M.II rootstocks. The trees were not staked or otherwise supported.

Pruning and shaping. Well-feathered maiden trees were chosen for planting. Each leading shoot was headed off at about two feet from the ground and much of the feather was used to form initial small branches; others formed the earliest cropping wood.

No summer pruning was done during the first year after planting-out and winter pruning consisted of shortening the leader to approximately 12 in. and tipping some of the laterals to form small branches.

As with other areas in the same field, the soil fertility pattern varied markedly and in an erratic manner and this resulted in some vigorous trees whereas others did not grow well. The general standard of development of the dwarf pyramids was satisfactory, however, at the end of the fifth year although a drastic check in growth had followed grassing down. There was a severe drop of young fruits after the second post-blossom lime sulphur spraying in the fourth and fifth years, perhaps related to the low nitrogen status of the trees in these two seasons following grassing down.

One of the aims in the pruning programme was to dispense with summer pruning as far as possible ; this was achieved up to the sixth and seventh years, by which time the pyramids reached a height of about 6 ft. At this height top-growth was stopped, mostly by bending down, in the summer, the leaders and a few of the additional strong shoots in the tops of the pyramids. Laterals in the lower parts were bent in successively each summer, especially those growing outwards into the alley-ways. These were twisted back to one another, thus keeping the pyramids trained in a hedge-like form that caused no hindrance to implements.

Difficulties were met wherever the pyramids became overcrowded with lateral shoots and shading was made more acute by the policy of tying down leaders and other shoots in the tops. Judicious thinning out of the older branches, the bending in of fewer laterals and a resort to summer pruning, where necessary, corrected this overcrowding. In the tenth year the pyramids were in a satisfactory state of growth with the exception of a few trees in which over-vigorous growth had been evident from the beginning; ring-barking in the seventh year failed to check this.

Manuring. Manurial treatment was similar to that used for the bush trees until the eighth to tenth years when the nitrogen was halved.

Grassing down. During the second season after planting, growth was very vigorous and some summer pruning was done to reduce vigour. As this vigorous growth continued in the third year the plot was grassed down in August to Wild White clover and Timothy S.50 in an attempt to check vigour, and nitrogen was omitted prior to grassing down.

Spraying. The spray programme was similar to that used on the cordons.

Notes on damage by canker and by weather conditions.

During the period under review six trees of Cox and two of Winston, all on M.II, in planting A were killed by canker (*Nectria*) in the first year ; in B, four Cox on M.II and ten on M.IX were grubbed for the same reason and replaced with 2-year-old trees. Fourteen Cox trees on M.IX were replaced up to the fifth year, after which

there were no further replacements of trees on this rootstock. During the last five years there were ten further losses but the tree positions were left vacant as it was planned that filler trees on M.IX would be thinned in about the tenth year.

In 1954 severe frost which occurred between 26th January and 7th February resulted in the splitting of the stems of 77 trees of Cox of which 74 were on M.IX. Bark injury was confined to the South sides of the tree stems and practically no trees with stem cankers were damaged. No splitting occurred on any of the cordon or dwarf pyramid trees.

Severe drought periods in 1955 and 1956 and a less severe period in 1957 resulted in the serious cracking of Cox fruits from trees on M.IX rootstock only; in 1956 leaf

TABLE II.

Annual and total crop yields in bushels per acre for each system of planting over the first ten years.

Variety	Age of plantation	System and number of trees per acre					
		A Bush trees 75	*B* Bush trees with fillers			*C* Cordons 1815	*D* Dwarf pyramids 1361
			Bush trees 75	Fillers 227	Total 302		
Cox's Orange Pippin ..	2	—	—	3	3	117	41
	3	3	1	19	20	109	35
	4	4	3	23	26	117	7
	5	3	6	24	30	68	34
	6	45	48	93	141	204	221
	7	76	68	167	235	185	547
	8	65	95	125	220	169	268
	9	249	208	200	408	251	549
	10	261	287	361	648	517	605
	Total	706	716	1,015	1,731	1,737	2,307
Winston	2	—	—	4	4	172	40
	3	4	5	30	35	108	80
	4	6	6	36	42	184	12
	5	23	18	99	117	160	220
	6	37	39	124	163	212	96
	7	82	63	248	311	272	692
	8	53	66	224	290	232	336
	9	154	163	342	505	176	532
	10	199	238	324	562	440	564
	Total	558	598	1,431	2,029	1,956	2,572
Laxton's Superb ..	2	—	—	3	3		
	3	11	11	39	50		
	4	6	6	24	30		
	5	40	46	122	168		
	6	39	23	21	44		
	7	241	266	226	492		
	8	16	29	29	58		
	9	328	277	278	555		
	10	124	121	60	181		
	Total	805	779	802	1,581		

drop was marked on trees of Cox and Winston on M.II but there was none on trees on M.IX.

Hail damage to ripening fruits was general over all systems in 1954 and resulted in much down-grading of the fruit.

RESULTS.

Crops from each tree, under each system, were recorded annually in pounds and from these figures the yields in bushels per acre were computed. The yields obtained over the first ten years are given in Table II and illustrated in Fig. 1. In presenting these data no allowance has been made for replacements or spaces in the plantation ; the figures therefore give the yield of apples that would be obtained off *an acre of land* under each of the planting systems under review and they indicate what might well be expected on any normal fruit farm where the vicissitudes contingent upon fruitgrowing would be met over the years.

Table II shows that the crops harvested from bush trees in systems A and B during the first ten years were approximately the same. In the late autumn of the tenth year all fillers except the one in the centre of each permanent square were removed from B and it was then noticeable that they had had an effect on the shape of the permanent trees, which were smaller and less spreading than those in A. The effect of this may be reflected in crops over the next few years.

The fillers on M.IX in B contributed substantially to the yield of fruit from the seventh year onwards. The fact that they had to be grubbed in the tenth year, because of competition for space with the permanent trees, demonstrates the doubtful economic value of such interplanting : in the long term it would probably be better to plant dwarf bush apples alone in a separate plantation.

Varietal performance.

Cox. Up to and including the fifth year, during which time the bush trees were being shaped, the two intensive systems (C and D of Table II) showed higher yields, as was to be expected.

By the ninth and tenth years the wide-planted bush trees on M.II were producing approximately 250 bushels per acre. In the planting with fillers the permanent bush trees were also producing around 250 bushels ; the dwarf bushes as fillers averaged 200 bushels per acre from the seventh to tenth years inclusive. The earlier marketing of fruits from trees on M.IX as compared with those from M.II coincided, over several years, with seasonal high prices.

The cordons averaged 200 bushels per acre in the sixth to ninth years inclusive and in the tenth year the crop rose to over 500 bushels.

The dwarf pyramids cropped at over 200 bushels per acre in the sixth year and for the seventh to tenth years the average was approximately 500 bushels.

Winston on M.II cropped relatively lightly when compared with trees on M.IX and a like difference was evident in size and colour and therefore in quality of the fruit. It was not until the ninth year that cropping on M.II reached around 150 bushels per acre; it had reached only 200 bushels in the tenth season. By contrast, trees on M.IX produced 250 bushels per acre in the seventh year, a rate of production well maintained since.

The cordons produced 200 bushels per acre in the sixth year and approximately 280 bushels over each of the following four years.

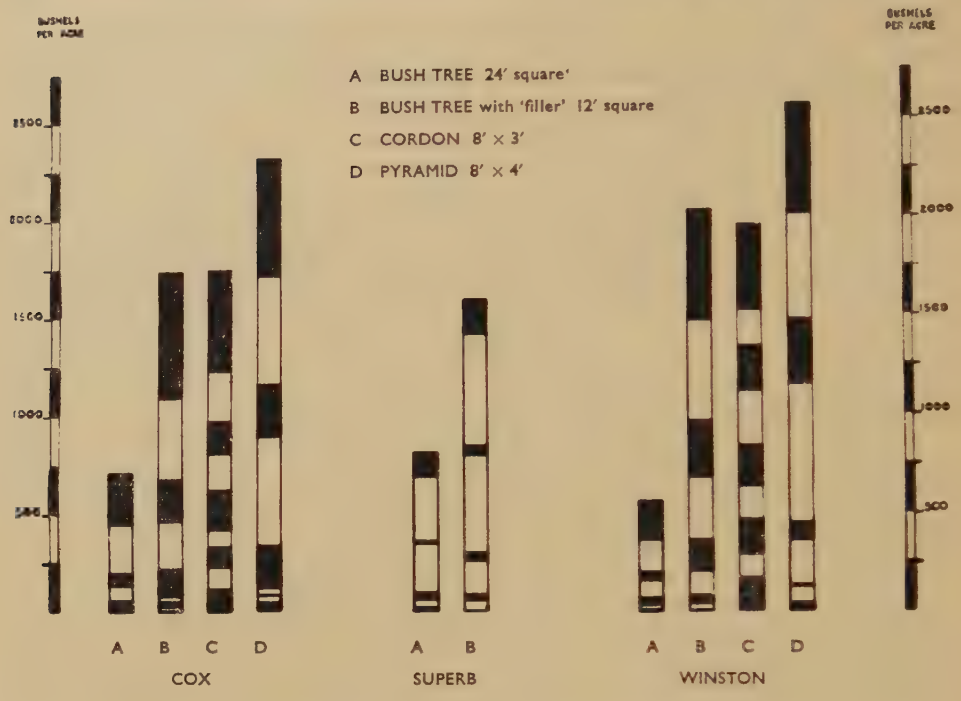

FIG. 1.
Planting systems. Annual and total yields, 1949-57.

In the fifth year the dwarf pyramids gave a crop of more than 200 bushels and, after a low yield in the sixth year, an average of over 500 bushels per acre was picked in the seventh to tenth years.

Superb was grown as bush trees or dwarf filler bushes only. Fillers on M.IX gave 122 bushels per acre in the fifth year—a heavy crop for small trees—and the trees subsequently became markedly biennial in cropping habit. In the sixth year the crop fell to 21 bushels per acre but in the seventh season it reached 226 bushels. The average crop over the last four seasons was 150 bushels.

Trees on M.II rootstock also fell into a biennial habit and trees in A and B averaged about 170 bushels per acre in the seventh to tenth years.

Whilst drawing no definite conclusions at this stage, the authors suggest that the dwarf pyramid system could profitably receive greater attention by the apple (and pear) growing industry. In comparison with extensive methods, the relatively higher costs of planting and pruning are more than offset by early and heavy cropping and by the fact that all operations can be carried out within easy reach of the ground. Fruit quality, as assessed by size and colour, compares favourably with that obtainable from wider spaced trees. The constant introduction of better machinery, designed for use in restricted conditions, offers the grower of dwarf pyramids a means of reducing the extra costs inherent in the management of closely planted trees and makes such intensive systems an attractive alternative to more extensive methods in these days of land shortage.

SUMMARY.

The development and cropping over the first 10 years of apple trees grown under four planting systems are described. Three dessert varieties on two Malling rootstocks were grown in the South-West with an average rainfall of 36 in.

The bush-tree plantation interplanted with filler bushes became overcrowded by the tenth year.

In total crop yield, the intensive systems showed a marked lead, attaining by the fifth or sixth year a level of 200 bushels or more per acre, a yield not reached under the extensive systems until the ninth or tenth year, the dwarf bushes cropping at an intermediate level.

The variety Winston cropped heavily as filler, dwarf pyramid and cordon trees. Fruit size and colour, from bush trees on M.II rootstock, especially in the latter half of the period, were below normal standards, only dwarf bushes on M.IX producing heavy crops of good size and colour throughout.

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EFFECTS OF SOIL MOISTURE ON THE YIELD AND QUALITY OF TURNIPS

II. RESPONSE AT DIFFERENT GROWTH STAGES

By G. STANHILL
National Vegetable Research Station, Wellesbourne, Warwick

In a previous paper (Stanhill, 1958) the effects of three different soil moisture regimes, maintained throughout the life of a crop of turnips, were described and it was shown that the greatest yield was obtained when the soil was maintained at field capacity by daily watering.

When irrigation is used as a supplementary source of soil moisture such a treatment is not commercially practicable. It is important, therefore, to know how a crop will respond to wet or dry soil conditions at different stages of growth so that the water, equipment and labour available for irrigation may be applied to the best advantage.

Preliminary experiments were carried out in 1954 to compare the final yields of turnip crops, when a dry period was imposed at three different growth stages, with the yield from a crop given daily irrigation throughout its growth. In two experiments the greatest depression in yield was caused when the dry period was imposed during the final stages of growth, i.e. when the edible roots were swelling. There was a smaller depression when water was withheld in the early seedling stage, but there was a significant increase in yield over the control when irrigation was withheld during the second growth stage before root swelling had begun.

These results indicated that there were periods of special moisture sensitivity and the experiment described in this paper was designed to investigate in greater detail the response of the turnip crop to short periods of wet or dry soil conditions at eight different growth stages.

Experimental methods.

Cultural details and experimental layout.

The experimental site and cultural methods used were similar to those previously described (Stanhill, 1958). Turnip seed of the variety Early White Milan was sown in rows 25 ft. long and 1 ft. apart and, as soon as the plants were large enough to handle, they were singled to 9 in. apart in the rows.

The experimental layout consisted of six randomized blocks of two plots, one for the dry and one for the wet treatment. Each plot contained eight pairs of rows, each pair of rows being sown in regular weekly sequence of eight sowing dates (see Table I). Every sub-plot therefore consisted of one pair of rows.

Treatment details.

Immediately after the last sowing had been made the two treatments (wet and dry) were started and were continued from 4th July to 25th July. At the end of this period the plants from the first sowing were harvested. Subsequent harvests were made at weekly intervals so that all plants were harvested 10 weeks after sowing. The different plant conditions at the beginning and end of the treatment period are described in Table I.

TABLE I.

Calendar of operations and condition of plants during treatments (1955).

Growth stage	Date of sowing	Days before emergence	Beginning of treatment 4th July		End of treatment 25th July		Date of harvest
			Age in days	Condition of plant	Age in days	Condition of plant	
1	4th July	5	0	Seed	21	Roots beginning to swell, seven leaves	12th Sept.
2	27th June	4	7	Cotyledons expanded	28	Eight leaves	5th Sept.
3	20th June	6	14	Two true leaves	35	Ten leaves	29th Aug.
4	13th June	7	21	Four leaves	42	Twelve leaves	22nd Aug.
5	6th June	7	28	Roots beginning to swell, seven leaves	49	Fourteen leaves	15th Aug.
6	30th May	7	35	Eight leaves	56	Sixteen leaves	8th Aug.
7	23rd May	7	42	Eleven leaves	63	Sixteen leaves	1st Aug.
8	16th May	10	49	Twelve leaves	70	Seventeen leaves	25th July

The two treatments were as follows :

Dry. The plots were given no irrigation and were sheltered from rainfall for the three weeks of treatment. At the end of this period they were restored to field capacity, the amount of water required being calculated from the moisture content of soil samples taken to the full depth of the root zone in each sub-plot.

Wet. At the beginning of the period of treatment the plots were watered to bring them to field capacity and were maintained in this state by daily irrigation for three weeks. The amount of water applied daily was equal to the evaporation of the preceding day calculated from local meteorological data (Penman, 1948).

All the plots were protected from rain during the three-week period of treatment by means of mobile glass shelters but, as these were used only once, their effect on plant growth (Stanhill, 1958) can be ignored.

Soil moisture status.

Before the experimental treatments began, rainfall was frequent and sufficient to prevent the depletion of more than 30 per cent. of the available water in the driest of the sub-plots. Soil samples taken after the treatments ended showed that the soil moisture content had not reached the permanent wilting point within the root zone on any of the sub-plots. Measurements made during the period of treatment

showed that, while all the sub-plots receiving the wet treatment remained at the same moisture status (field capacity), the soil moisture status of the sub-plots given the dry treatment differed according to the size of the plants, as might be expected. At the end of the dry treatment period the driest sub-plots (those of the first sowing) had 20 per cent. of available water remaining in the root zone as against 33 per cent. for the last sown sub-plots receiving the same treatment. It seems unlikely, however, that this comparatively small difference, lasting for less than three weeks, would obscure any marked difference in the plants' response to the two treatments.

After the treatments were finished, all plots were irrigated at weekly intervals with enough water to replace the calculated soil moisture loss of the preceding week.

Plant growth measurements.

The fresh weights of leaves and edible roots were determined from transect samples at the beginning and end of the three weeks of treatment. The numbers of green and of senescent leaves more than one quarter of an inch long were also counted.

At the eight harvests the dry weight of leaves and of edible roots and the number of plants with a visible inflorescence were recorded in addition to the above measurements. The total leaf area of the plants was calculated from regression equations relating the leaf area to the leaf fresh weight of a random sample of plants taken from each sub-plot when harvested. The equations were all highly significant with correlation coefficients greater than 0·98.

At each harvest the quality of the edible roots from the two treatments was compared in triangular tasting tests. The members of a tasting panel were asked to identify the odd sample among three dishes of diced cooked turnips, of which two were replicate samples from plots given one treatment, while a third dish contained a sample from plots given the other. The panel stated their reasons for selecting the odd sample and the significance of the results was tested by means of the tables given by Roessler *et al.* (1948).

EXPERIMENTAL RESULTS.

Water application, total evapo-transpiration and water-use ratio.

Each plot given the wet treatment received 3·83 in. of water during the three weeks of that treatment, and this led to an average increase in evapo-transpiration of 2·90 in. during the whole ten weeks of growth compared with that in plots given the dry treatment. Although all sowings given the wet treatment received the same extra amount of water, the increase in evapo-transpiration varied considerably between the different sowings and was linearly related to the growth stage at the time of treatment (Table II). Evapo-transpiration was calculated from records of rainfall, water application and soil moisture determinations made at sowing and final harvest. The measured water loss from an evaporation tank is given in Table II as an indication of the intensity of the evaporating conditions during the growth of the eight sowings.

The water-use ratio was calculated by dividing the total evapo-transpiration per plant by the dry weight per plant (Table II). At all growth stages, plants receiving the dry treatment made more efficient use of water (inverse of water-use ratio) than those given the wet treatment at the same growth stage. Differences in water-use ratio between the wet and dry treatments were greatest when these were imposed during early growth stages.

TABLE II.

Water application (in.), total evapo-transpiration (in.) and water-use ratio.

	Treatment	Growth stage (see Table I)								Mean
		1	2	3	4	5	6	7	8	
Water application	Dry	4·42	4·32	5·34	5·18	5·18	5·26	4·63	4·47	4·85
	Wet	8·25	8·15	9·17	9·01	9·01	9·09	8·46	8·30	8·69
Total evapo-transpiration	Dry	7·27	6·97	7·69	7·13	8·53	8·11	7·78	9·22	7·84
	Wet	11·45	11·00	11·32	10·96	12·01	10·34	9·71	9·10	10·74
Difference		*4·18*	*4·03*	*3·63*	*3·83*	*3·48*	*2·23*	*1·93*	*−0·12*	*2·90*
Water-use ratio	Dry	1,252	529	450	378	348	265	286	—	501
	Wet	1,639	858	678	573	429	325	296	—	686
Evaporation from open water surface		8·72	8·88	8·72	8·50	8·72	8·52	8·50	8·19	8·62

Growth data.

The effects of the two treatments were separated into (*a*) those which occurred while the differential watering was in progress, and (*b*) those delayed effects which occurred between the end of the treatment and harvest. Fig. 1 shows for (*a*) and for (*b*) the increase in the total fresh weight of plants given the wet treatment as a percentage of the increase in fresh weight of plants receiving the dry treatment at the same growth stage.

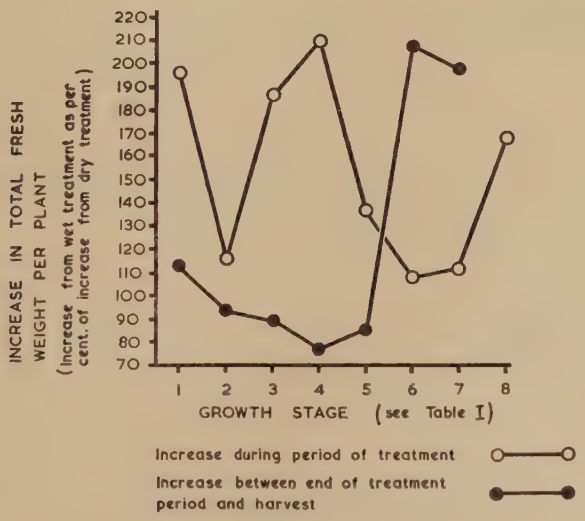

FIG. 1.

Effect of growth stage at time of treatment on increase in total fresh weight during and after period of treatment.

Final harvest data.

Leaf growth. The mean effect of all the wet treatments, as compared with that of all the dry treatments, was to increase the leaf fresh weight per plant at harvest by 10 per cent. The difference was greatest, and was statistically significant, when the treatments were applied at the last growth stage (Fig. 2a). There were indica-

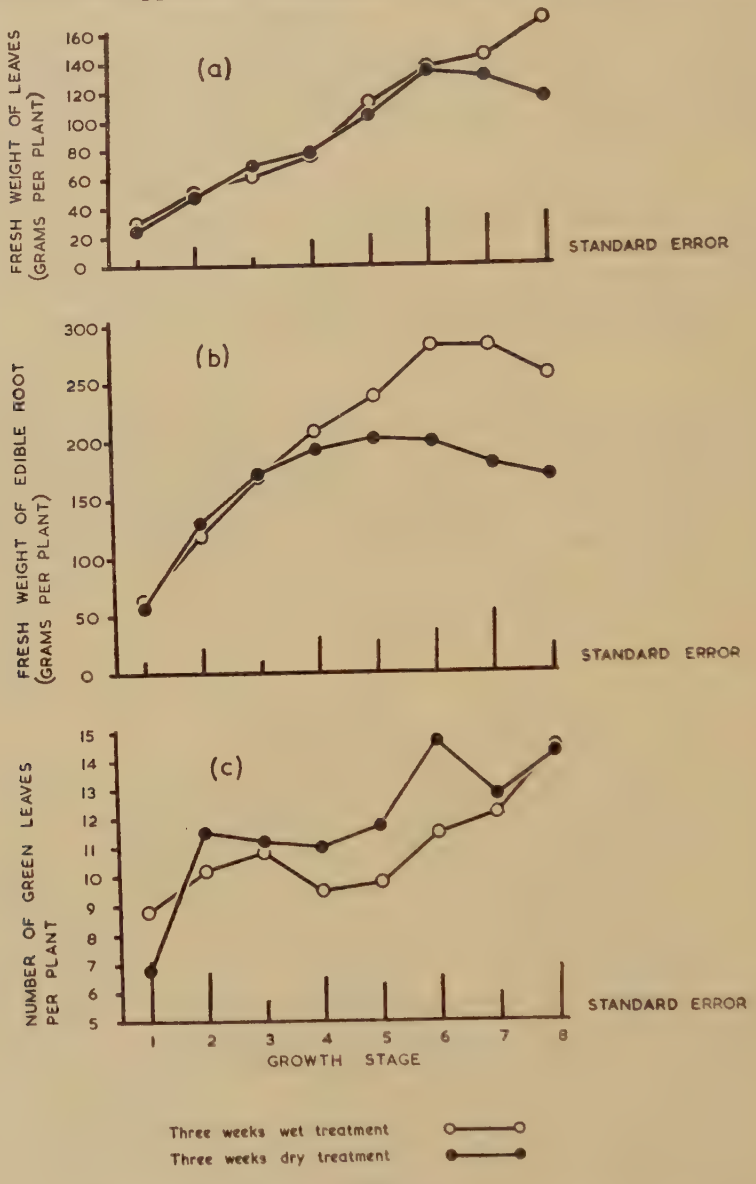

FIG. 2.
Effect of treatments on the fresh weight and number of leaves, and on the root weight at harvest.

tions also that the differences became progressively smaller as the treatments were applied at earlier growth stages ; when applied at the stage between emergence of the second true leaf and beginning of root swelling, the wet treatment produced a slightly lower leaf fresh weight than the dry treatment.

The effects of the treatment at different growth stages on the leaf dry weight per plant were very similar to those on the fresh weight. Hence the treatments had not affected the water content of the leaves.

The average leaf area at harvest of plants given the wet treatment was 20 per cent. greater than that of plants given the dry treatment. The interaction between treatments and growth stages was similar to that found with leaf weight although the depressing effect of the wet treatment applied at stage 3 was more marked (Table III). Leaf fresh weight per unit area was only slightly affected by the treatments and did not differ between plants of the eight sowing dates.

TABLE III.

Effect of treatments at different stages on leaf area (sq. cm.) per plant.

Treatment	Growth stage								Mean
	1	2	3	4	5	6	7	8	
Dry ..	896	1,804	2,674	2,087	3,496	4,882	4,715	4,918	3,089
Wet ..	1,060	1,976	2,393	2,510	4,225	5,502	6,315	6,296	3,796

The number of green leaves per plant was slightly, but not significantly, greater in plants given the dry treatment than in plants given the wet treatment, in each of the growth stages except the first and last (Fig. 2c). The wet treatment significantly increased the proportion of senescent leaves at harvest when the treatment was applied after roots had begun to swell ; when applied at earlier growth stages the wet treatment reduced this proportion (Table IV).

TABLE IV.

Effect of treatments at different stages on percentage of senescent leaves at harvest.

Treatment	Growth stage								Mean
	1	2	3	4	5	6	7	8	
Dry ..	52·4	35·3	32·7	34·5	22·0	16·9	26·0	18·6	39·6
Wet ..	36·4	29·7	30·8	37·5	29·0	24·8	31·1	17·1	29·5

The treatments had no effect on the proportion of plants flowering at harvest.

Root growth. The fresh weight of edible roots was 20 per cent. greater from plants which received a wet period of treatment than from plants given a dry period. The effect of the two treatments at different growth stages was similar to that found for leaf weight and area, although for root growth the effects of the treatments were

larger and were statistically significant in a greater number of cases (Fig. 2b). The dry weight of roots showed a similar trend of response to treatment at the different growth stages.

Root quality. The tasting panel detected significant differences between cooked roots from the two treatments only when they were applied in the last two growth stages, i.e. during the last four weeks before harvest. Roots from plots given the dry treatment were described by the majority of the tasting panel members as being " more strongly flavoured " and having a " tougher texture " with " less watery flesh " than roots from plots which had received the corresponding wet treatment.

DISCUSSION.

Total evapo-transpiration and the efficiency of water use.

The large increase in total evapo-transpiration from plots watered in the early growth stages was probably caused by increased evaporation from the wetted bare soil surface (Russell, 1950). As the plant cover increased in the later growth stages, transpiration became the dominant factor in evapo-transpiration (Stanhill, 1956). The fact that the treatments then had little effect on evapo-transpiration, despite differences of up to 70 per cent. in available soil moisture, suggests that transpiration rate was not affected by differences in soil moisture content over a large part of the available water range.

There was a high correlation between water loss from the open water surface of the evaporation tank and loss by evapo-transpiration from plots during the same period. The correlation was highest for plots given the wet treatment. The mean loss by evapo-transpiration was 20 per cent. greater from the wet plots, and 10 per cent. less from the dry plots, than from the open water surface. These high proportions of evapo-transpiration to evaporation may have been caused by the lack of homogeneity in the crop surface as a result of the successional sowings ; this possibly increased air turbulence above the plots, thus increasing the evapo-transpiration rate.

Harvest yields.

In many of the harvests the effects of the two treatments did not differ significantly. However, when the trend in the results of all eight harvests is considered

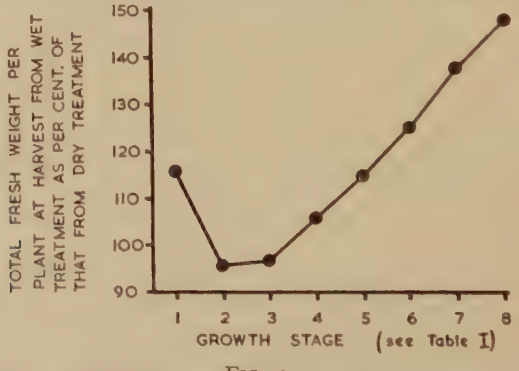

FIG. 3.
Effect of growth stage at time of treatment on total fresh weight at harvest.

(Fig. 3), it is clear that three distinct phases can be distinguished according to the plant's response to the wet treatment. The type of response was similar to that found in the two earlier experiments (see p. 264).

Phase I. This covered a relatively short period, from the time of sowing until the cotyledons had expanded and the first true leaf was visible. The wet treatment applied during this phase increased the fresh and dry weights of the plants at harvest and the weight of the leaves was affected somewhat more than that of the roots. The wet treatment also increased the total leaf area and the number of green leaves at harvest. These results confirm the view generally held that crops do not fully recover from checks to growth caused by unfavourable conditions in the early seedling stage.

Phase II. This ended when the edible roots were just starting to swell and when the fourth true leaf had emerged. The wet treatment applied during this phase caused a small depression in the final yield of both leaves and roots as compared with the yield from plots given the corresponding dry period. Fig. 1 shows that this resulted from two opposite effects. When the wet treatments were applied, growth (especially leaf growth) was stimulated and it was not until after the wet treatments had ended that the growth was depressed as compared with that of plants given the dry treatments.

A number of experiments (Volodarski and Bykouskaja, 1954 ; Gates, 1955 ; Owen and Watson, 1956) have shown that plants subjected to dry soil conditions for a short period during early stages of growth grew ultimately to a greater size than plants grown in soil kept continuously moist. Petrie *et al.* (1943) compared the dry weight and leaf area of tobacco plants given dry periods at different growth stages with that of plants growing continuously in soil maintained near field capacity by frequent watering. They found that the highest yield resulted from a dry period of one week imposed three weeks after planting. The leaf protein nitrogen of the tobacco plants receiving the early temporary drought treatment exceeded that of the controls, and the authors suggest that this increased nitrogen content led to an increased growth rate following the resumption of watering.

To find whether the same explanation would account for the increase in turnip yield caused by the dry treatment in Phase II, the treatments were repeated during the following summer (1956). Leaf and edible root samples taken at the beginning and end of Phase II, and also at the final harvest, were analysed for the total nitrogen content.

At the end of the three weeks of wet treatment the plants had only half the nitrogen content of those which had been given the dry treatment, and a difference persisted up to the final harvest (Fig. 4). The treatment also altered the relative proportion of nitrogen in the leaves and in the edible roots. With the wet treatment most of the extra nitrogen accumulated during Phase II was stored in the roots, whereas in plants given the dry treatment most of the nitrogen increment was found in the leaves. A further series of nitrogen analyses carried out on turnip plants grown under a continuous wet regime confirmed that, when the edible roots started to swell, the increase in leaf nitrogen content was checked and, at the same time, there was an increase in the nitrogen content of the edible roots. When a dry period was imposed at this growth stage, there was an increase in the total nitrogen content of the plant (Stanhill, 1958) and the reduction in the nitrogen supply to the leaves was delayed (Fig. 4).

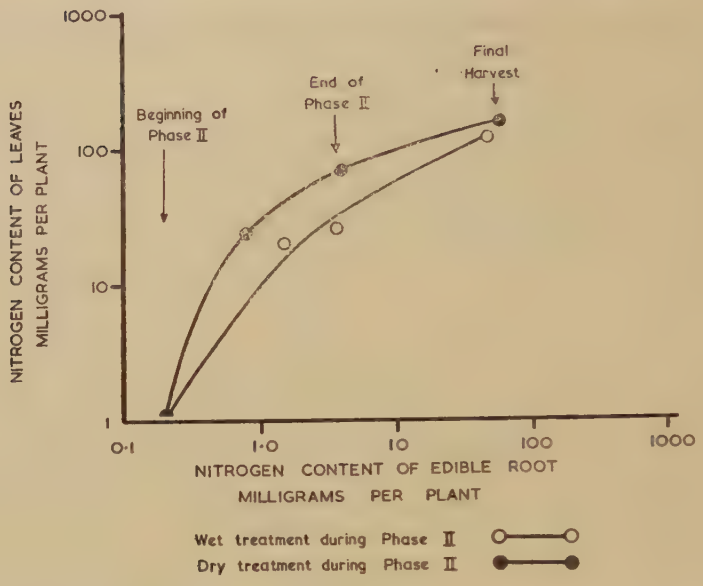

FIG. 4.
Distribution of nitrogen within the plant, as affected by wet and dry treatments.

The probable explanation, therefore, of the yield depression caused by a wet period when root swelling began, is that the plentiful water supply during Phase II caused the observed luxuriant leaf growth during the time of treatment. When the wet period ended, the reduction in water supply coincided with a reduction in the supply of nitrogen to the leaves and the combined effect was to check further leaf growth and to limit final yield.

In plants given the dry treatment during Phase II the nitrogen content of the leaves was considerably greater than in plants given the wet treatment and, when watering was resumed, their growth rate exceeded that of plants from the wet plots.

Phase III. During this stage, which covered the period of edible root development, the treatments had their greatest effect on yield. A large increase in root weight and a rather smaller increase in leaf weight were caused by the wet treatment, the effect of which became greater the later it was applied—from a 5 per cent. increase in total fresh weight when applied in the first three weeks of Phase III to a 50 per cent. increase when the treatment was applied in the last three weeks before harvest.

It was not until the last two growth stages of the third phase that the quality of the roots was affected by the treatments. The effects then were similar to those observed when turnips were subjected to different soil moisture regimes maintained throughout the life of the crop (Stanhill, 1958).

Climatic correlation with yield.

The technique of successional sowing and harvesting used in this experiment enabled the effect of climatic environment on growth to be separated from that of plant age. The general effect of season of growth on final yield is apparent in Fig. 3.

The climatic correlations with the total fresh weight at harvest of plants receiving a period of wet treatment were briefly as follows :

Day degrees. There was a highly significant *negative* correlation ($r = -0{\cdot}895$) between weight in grams per plant at harvest (y) and accumulated day degrees above a base line of 42° F. (x). The linear regression line fitted was of the form $y = -0{\cdot}726x + 837{\cdot}5$. There were indications of curvilinearity below 600 day degrees. This inverse relationship between temperature and growth agrees well with the general experience that the turnip grows best in cool climates.

Net radiation. There was a positive relationship between weight in grams per plant at harvest (y) and the calculated net radiation (z) in gram calories per sq. cm. (incoming short-wave radiation minus outgoing long wave radiation). The quadratic equation

$$y = 1{\cdot}376\,(z/100)^2 - 4{\cdot}672\,z + 39{,}775$$

fitted the data adequately. The positive relationship is in marked contrast with that of temperature, suggesting that it is the visible light radiation which is positively correlated with yield, and indicating that conditions of high light intensity and moderate temperature are the most favourable for growth of the turnip crop.

Potential evapo-transpiration. There was a positive relationship between yield and potential evapo-transpiration calculated by Penman's method (1948). The relationship was similar to that found with net radiation but showed a greater scatter, suggesting that, as net radiation is the predominant factor in determining potential evapo-transpiration during the summer, it is also the cause of the relationship between potential evapo-transpiration and growth.

Actual evapo-transpiration. The variation in the water loss per unit plant dry weight indicated that there was no simple relationship between actual water loss and growth.

SUMMARY.

1. Plots of turnips at eight different stages of growth were subjected to a three-week period of either daily irrigation or no irrigation. The treated plants were shielded from rainfall during this period. Before and after the period of treatment, watering was sufficient to prevent any large soil moisture deficit from arising.

2. The different responses in yield brought about by a period of wet treatment applied at different ages could be related to three distinct phases of growth of the plants.

3. During the first phase, when the plants were seedlings, a wet period increased the weight of leaves and edible roots at harvest.

4. During the second phase, when root swelling had started, a wet period depressed the yield at harvest. This was attributed to changes in nitrogen utilization within the plant which occurred during this phase.

5. During the third phase, which extended to harvest, a wet treatment produced the greatest increase in final yield ; the later the time of wet treatment in this third phase the greater was the effect.

6. The quality of cooked turnip roots was affected only by those watering treatments which were applied in the four weeks preceding harvest. During this stage a wet treatment gave the roots a milder flavour and smoother texture than a dry treatment.

7. The wet treatment increased the mean evapo-transpiration. The increase was greatest when the treatment was applied in the early growth stages before there was appreciable plant cover and became negligible when the crop canopy covered the soil surface. It was attributed to the increased evaporation rate from wet bare soil rather than to any effect on transpiration rate.

8. Under the near-optimum soil moisture conditions of the wet plots, the yield of turnips was negatively correlated with temperature above 600 day degrees and was positively correlated with net radiation.

ACKNOWLEDGMENTS.

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HYDRANGEA RINGSPOT IN BRITAIN

By M. HOLLINGS
Plant Pathology Laboratory, Harpenden, Herts

HYDRANGEA ringspot was first described by Brierley and Smith (1952) in the United States ; further details of the causal virus were given by Brierley (1954), Brierley and Lorentz (1956, 1957) and by Sisler *et al.* (1957).

Brierley isolated the virus from some plants of all nine varieties of hydrangea which he tested ; most of these varieties showed slight or no symptoms when infected. Hydrangea ringspot virus was readily transmitted by mechanical inoculation of sap, and by first cutting infected and then healthy plants with the same knife, but not through the seed. Sisler *et al.* found specific rod-shaped particles of variable length and about 16 mμ wide in infected plants. The virus in some ways resembled potato virus X, but they made no protection or serological tests to determine whether the two are related.

Hydrangea ringspot virus was detected at the Plant Pathology Laboratory, Harpenden, in February 1957, in specimens from Mr. H. J. Wilcox, N.A.A.S. Advisory Pathologist, Reading, and was later found in hydrangea plants from several other parts of the country. This paper lists some host plants and describes properties of the virus.

Hydrangeas were grown in unheated gauze houses, other test plants in insect-proof glasshouses at 65–70° F. John Innes No. 2 potting compost was used for all plants. Mechanical inoculations were made according to standard techniques ; infected tissues were macerated with a little M/15 phosphate buffer at pH 7·0 and " Celite " powder was added to the inoculum before the leaves of test plants were gently wiped with the forefinger wet with inoculum.

SYMPTOMS AND OCCURRENCE ON HYDRANGEAS.

Hydrangea ringspot virus causes local lesions on *Chenopodium amaranticolor*, *Gomphrena globosa*, *Cucumis sativus* and several other plants, but fails to infect *Phaseolus vulgaris*, *Nicotiana tabacum* or any other Solanaceous plant tested. A virus with these properties was found in hydrangea plants showing symptoms varying from chlorotic spots and rings on the older leaves to leaf crinkling and asymmetry, with some necrotic stem pitting.

Inarch grafts were made, in April 1957, to young hydrangea plants of variety Holdstein free from the virus. In addition, mechanical inoculations were made to hydrangea plants of the same clone. The ringspot virus was detected by inoculation to *Gomphrena* in two out of three inoculated plants and in both grafted plants after 7 weeks. Symptoms consisted of very slight chlorotic spots on the younger leaves after 4–7 months ; after 7½ months the leaves senesced and fell from the plants. A few of the older leaves developed occasional necrotic spots and rings shortly before they fell (Fig. 1) ; no such symptoms appeared on the uninfected control plants.

Mechanical inoculation to two plants of an unknown variety of hydrangea induced some brown spots and rings on the mature leaves after 5 months, with some buckling and distortion (Fig. 2). Inoculations from all these plants to tobacco and *Gomphrena* detected hydrangea ringspot virus only.

This virus was isolated from young leaves of hydrangea plants growing in private gardens in Nottingham, Harpenden and Marlborough. Some of the infected plants showed no symptoms. No virus was detected in other hydrangea plants tested from these and other places.

HOST RANGE AND SYMPTOMS.

All test plants were checked for symptomless infection by return inoculation to *Gomphrena* or *Chenopodium* from inoculated (local) and non-inoculated (systemic) leaves. The list of plants examined is as follows :

Aizoaceae : *Tetragonia expansa* Murr., small chlorotic or semi-necrotic local spots and rings after 10 days, later enlarging slightly (Fig. 3).

Amarantaceae : *Amaranthus caudatus* L., numerous local chlorotic spots after 7–10 days (Fig. 4) ; *Celosia argentea* L., faint local chlorotic spots after 7–10 days, later becoming necrotic, reddish and distinct (Fig. 5) ; *Gomphrena globosa* L., numerous pale local necrotic dots after 3–5 days, later enlarging and often developing reddish margins (Fig. 6).

Boraginaceae : *Myosotis sylvatica* Hoffm., no infection.

Caryophyllaceae : *Dianthus barbatus* L., no infection ; *Stellaria media* Vil., few irregular etched local necrotic rings after 7 days.

Chenopodiaceae : *Beta vulgaris* L., very faint local chlorotic spots after 7–10 days ; *Chenopodium amaranticolor* Coste & Reyn., numerous local chlorotic dots, each with a central necrotic speck (Fig. 7) after 5–7 days ; *Spinacia oleracea* L., few faint local diffuse chlorotic spots after 2 weeks.

Compositae : *Bellis perennis* L., *Callistephus chinensis* Nees, *Chrysanthemum morifolium* Ramat. (vars. Blazing Gold, Mistletoe, Penrod), no infection ; *Helianthus annuus* L., local symptomless, virus in low concentration ; *Lactuca muralis* Gaertn., *L. sativa* L. (var. Cheshunt Early Giant), *Taraxacum officinale* Weber, *Zinnia elegans* Jacq., no infection.

Cruciferae : *Brassica oleracea* var. *acephala* L., *B. pekinensis* Rupr., *Cheiranthus cheiri* L., no infection.

Cucurbitaceae : *Cucumis sativus* L., few faint brown local spots after 1—2 weeks on inoculated cotyledons, inoculated true leaves with irregular necrotic spots and blotches.

Geraniaceae : *Geranium robertianum* L., *Pelargonium hortorum* Bailey, no infection.

Gramineae : *Avena sativa* L., no infection.

Leguminosae : *Phaseolus vulgaris* L. (var. Prince), *Pisum sativum* L. (var. Lincoln), *Vicia faba* L. (var. Green Masterpiece), no infection ; *Vigna sinensis* Savi. (var. Blackeye), indefinite local chlorosis after 2 weeks, one plant developing systemic chlorosis and leaf malformation and the virus being recoverable in low concentration from the young leaves.

Lythraceae : *Lythrum salicaria* L., no infection.

Phytolaccaceae : *Phytolacca americana* L., very few faint local chlorotic spots after 10–14 days, the virus not recoverable from these leaves although the inhibitor

in *Phytolacca* sap does not normally prevent infection of *Chenopodium* or *Gomphrena*.

Plantaginaceae: *Plantago lanceolata* L., local symptomless; virus in high concentration.

Polygonaceae: *Fagopyrum esculentum* Moench, local symptomless, virus in low concentration.

Portulacaceae: *Portulaca oleracea* L., local symptomless, virus in high concentration.

Primulaceae: *Cyclamen persicum* Mill., no infection; *Primula malacoides* Franch., local and systemic, symptomless, virus in high concentration.

Ranunculaceae: *Ranunculus repens* L., no infection.

Rubiaceae: *Galium aparine* L., no infection.

Scrophulariaceae: *Antirrhinum majus* L., few pale-brown necrotic spots after 10 days.

Solanaceae: *Datura stramonium* L., *Lycopersicon esculentum* Mill. (vars. Syston Cross and Kondine Red), *Nicotiana glutinosa* L., *N. rustica* L., *N. tabacum* L., *Petunia hybrida* Vilm., *Physalis floridana* Rydb., no infection.

Tropaeolaceae: *Tropaeolum majus* L., no infection.

Umbelliferae: *Apium graveolens* L. (var. Roi des Jaunes), *Petroselinum crispum* Nym., no infection.

Aphid transmission tests.

Primula malacoides was readily infected systemically with hydrangea ringspot virus, which reached high concentrations without causing any symptoms. As aphids fed much more readily on *Primula* than on *Hydrangea* leaves, *Primula* was used for aphid transmission tests. Attempts to transmit the virus from *Primula* to *Primula* by *Myzus persicae* (Sulz.) and *Macrosiphum euphorbiae* (Thos.) failed, whether aphids were given long or short acquisition feeds.

Properties *in vitro*.

Dilution end-point. Infected tissue was macerated in phosphate buffer and dilutions made on a weight to volume basis. Inoculations were made to *Chenopodium* and a little "Celite" was added to the inoculum before inoculation. The highest dilutions still infective were:

Hydrangea flowers, 1/10,000

Hydrangea young leaves, 1/10,000–1/25,000

Primula young leaves, 1/20,000–1/40,000

Thermal inactivation point. The virus was inactivated by heating to 75° C. for 10 minutes; in one test, infectivity was lost at 70° C. Considerable inactivation occurred at lower temperatures (Table I).

Survival in vitro. More than half the infectivity was lost when hydrangea leaf sap was stored at room temperature (about 18° C.) for 3 days, little remained after 21 days and none after 28 days. At 1° C. about half the infectivity was lost after 7 days, but some remained after 17 weeks. Shredded *Primula* leaves, dried over anhydrous calcium chloride at —15° C., remained infective for more than 8 months.

TABLE I.

Loss of infectivity after heating at different temperatures (° C.).

Source of inoculum	No. of lesions after 10 mins. at :							
	Lab. temp. (un-heated control)	45°	50°	55°	60°	65°	70°	75°
Hydrangea leaves ..	859	399	183	251	223	14	0	0
,, ,, ..	788	661	200	186	183	16	3	0
Primula leaves ..	1,174	820	601	596	234	96	14	0

Inactivation by chemicals. The virus was inactivated within 2 minutes by 5 per cent. tri-sodium orthophosphate solution, and by 50 per cent. alcohol within 60 minutes, though most of the infectivity survived 10 minutes' exposure to 50 per cent. alcohol.

INTRACELLULAR INCLUSION BODIES INDUCED BY HYDRANGEA RINGSPOT VIRUS.

Epidermal peelings from leaves, petioles and flower petals of hydrangea and *Primula* plants were examined for intracellular inclusions, after staining either in 0·5 per cent. phloxine, or by the phloxine-trypan-blue method of McWhorter (1941). No specific inclusions were seen in hydrangea, but chloroplasts were often clumped together in infected plants. Some peelings from infected petioles contained needle crystals, which were rare in healthy material.

The epidermal cells of infected *Primula* leaves contained very few inclusions, but hair cells often had oval or elongated vacuolate bodies not found in healthy plants, and which stained intensely with phloxine (Fig. 8). Discrete granules were sometimes clearly visible in these inclusions, which ranged in size from $32 \times 13\mu$, to $50 \times 11 \cdot 5\mu$. Nuclei varied between 16 and 25μ in diameter and occasionally two nuclei occurred in the same cell in infected plants. The distribution of inclusions was irregular in infected leaves ; some peelings contained inclusion bodies in nearly every basal hair cell and others contained very few.

SEROLOGICAL REACTIONS.

An antiserum was prepared against hydrangea ringspot virus by injecting partially purified preparations. Young infected hydrangea leaves were frozen for 6 days, minced, and about 60 ml. of sap expressed after thawing. The leaf residue was extracted with 15 ml. of phosphate buffer and, after the bulked fluids had been heated at 50° C. for 10 minutes, they were centrifuged at 7,500 G for 20 minutes. The supernatant fluid was then centrifuged at 75,000 G for 2½ hours and the resulting yellowish pellet suspended in 8 ml. distilled water plus 1 ml. phosphate buffer; this preparation was injected intravenously, in 4 graded doses at 3-day intervals, into a rabbit. Ten days after the last injection, the rabbit was bled and 0·1 per cent. merthiolate (sodium ethyl-mercuri-thiosalicylate) added as preservative. In precipitin tests in tubes, with 1 ml. of serum plus 1 ml. of clarified

sap, the titre of the serum was 1/160 and that of infected hydrangea sap 1/64. The precipitin tubes were incubated at 37° C., and the bulky flocculent precipitate developed in the first tubes after an hour. Micro-precipitin drop-tests were also successful. Single drops of antiserum diluted to 1/10 with saline were mixed with single drops of clarified sap, diluted 1/4 or 1/16 from infected hydrangea or primula leaves. Several such drops were placed on the bottom of petri dishes previously coated with 1 per cent. " Formvar " solution in chloroform and dried. The drops were covered with liquid paraffin to exclude air and incubated at room temperature for 24–48 hours, then examined under a low-power binocular microscope. After 24 hours, an opalescent jelly-like mass was visible in all the test drops, but none in the control drops (normal serum plus infective sap, and antiserum plus normal sap). The flagellar type precipitate indicates that the antigen is not isomorphic and its formation is consistent with the occurrence of rod-shaped particles in infective sap.

Gel-diffusion plates, using antiserum or sap mixed with equal volumes of liquid agar at about 45° C. and poured into wells in the solid agar of the petri dishes, showed no reaction. This method, based on that used by Björkland (1952) and later by the Dutch workers (van Slogteren, 1955), works well with several spherical plant viruses, but with very few rod-shaped ones.

Serological identity of different isolates of hydrangea ringspot virus.

Six isolates of the virus, obtained from different parts of the country, were tested against the antiserum in precipitin-tube tests ; all reacted well, though one isolate had a lower titre than the others, and there was some inhibition of the reaction at low dilutions of antigen, suggesting that fewer common antigenic units were present in this isolate.

Infected *Primula* sap also reacted with the antiserum but it was liable to precipitate spontaneously after about 12 hours, in contrast with clarified hydrangea sap.

Sisler *et al.* (1957) pointed out that hydrangea ringspot virus and potato virus X had some rather similar *in vitro* properties, and that both had rod-shaped particles. However, tobacco sap infected with two strains of potato virus X failed to react with hydrangea ringspot virus antiserum in either precipitin tube or micro-precipitin drop tests. Both strains of potato X reacted strongly with an antiserum to one of them, giving titres of 1/640 and 1/320. Hydrangea ringspot sap did not react with the potato virus X antiserum.

Protection tests with hydrangea ringspot virus and potato virus X.

No natural host plant has so far been found which can be infected systemically with both these viruses. Of the test plants used in the present work, *Primula malacoides* was systemically infected with hydrangea ringspot virus and was also susceptible to local infection with potato virus X. As neither virus causes symptoms in *Primula*, check inoculations to indicator plants are necessary to confirm infection. *Primula* plants were inoculated with hydrangea ringspot virus and after 5 weeks check inoculations were made from the young leaves to *Gomphrena*. All the *Primula* plants were found to be infected. Challenge inoculations with potato X virus were then made to these plants and, after 6 weeks, return inoculations to tobacco were made from the inoculated leaves. Potato virus X was detected in the inoculated leaves. The failure of hydrangea ringspot virus to protect against potato virus X confirms the conclusion from the serological tests that the two viruses are not related.

Particle form of hydrangea ringspot virus.

Rod-shaped particles were found in sap from infected hydrangeas. Expressed leaf sap was heat-clarified at 50° C. for 10 minutes, centrifuged at 7,500 G for 20 minutes, and drops of the supernatant fluid examined under an electron microscope after the preparations had been shadowed with platinum. Other preparations were examined after the supernatant fluid had been centrifuged at 75,000 G for 2 hours, and the resulting pellet re-suspended in a little distilled water. The particles seen in both types of preparation varied in length from 870 to 1,400 mμ and were about 16 mμ in diameter (Fig. 9). The transverse bands recorded by Sisler *et al.* were not visible in these preparations.

DISCUSSION.

The virus isolated from hydrangeas in England differs from the American isolates in failing to infect *Dianthus barbatus* ; but, as this plant is very variable and lines have been found resistant to certain carnation viruses, the difference probably has little significance. The other properties agree closely with those reported for the American virus and there is little doubt that it is the same or closely similar.

Hydrangea ringspot virus has been found in plants from widely separated areas in England and is probably present in many hydrangea stocks. Although some varieties showed no symptoms, at least in the first year of infection, others showed more severe damage than Brierley found in the varieties he worked with. Brierley isolated tomato ringspot virus quite frequently from hydrangeas in the U.S.A., and found it much more damaging to hydrangeas than hydrangea ringspot virus, but it was not present in any plant tested by the writer.

Hydrangea ringspot virus shows no close relationship to any of the better-known plant viruses, though in its particle form and stability *in vitro* it superficially resembles potato virus X. The vacuolate intracellular inclusions resulting from its presence in *Primula* plants are not unlike those described for potato virus X by Bawden and Sheffield (1944). Like potato X, it seems not to be aphid-transmitted but, as Brierley pointed out, its ability to spread on cutting knives is sufficient to explain its survival and spread. Also, hydrangeas are usually vegetatively propagated and, as many varieties in the United States show few or no symptoms, growers are not likely to discard infected plants.

The occurrence of more severe symptoms on some plants in England suggests that it is worth while for growers to rogue visibly affected plants and to clean cutting knives between working on different bushes.

SUMMARY.

Hydrangea ringspot virus, previously described in the United States of America, was found in plants of *Hydrangea macrophylla* Ser. from several places in England. Some naturally infected plants were symptomless, some had chlorotic spots and rings on the older leaves, and others had crinkled and misshapen leaves. Artificially infected hydrangea plants took 4–7 months to develop symptoms.

The virus infected 17 out of 49 plant species inoculated mechanically ; *Chenopodium amaranticolor* and *Gomphrena globosa* gave the most characteristic symptoms. It was not transmitted by *Myzus persicae*.

PLATE I

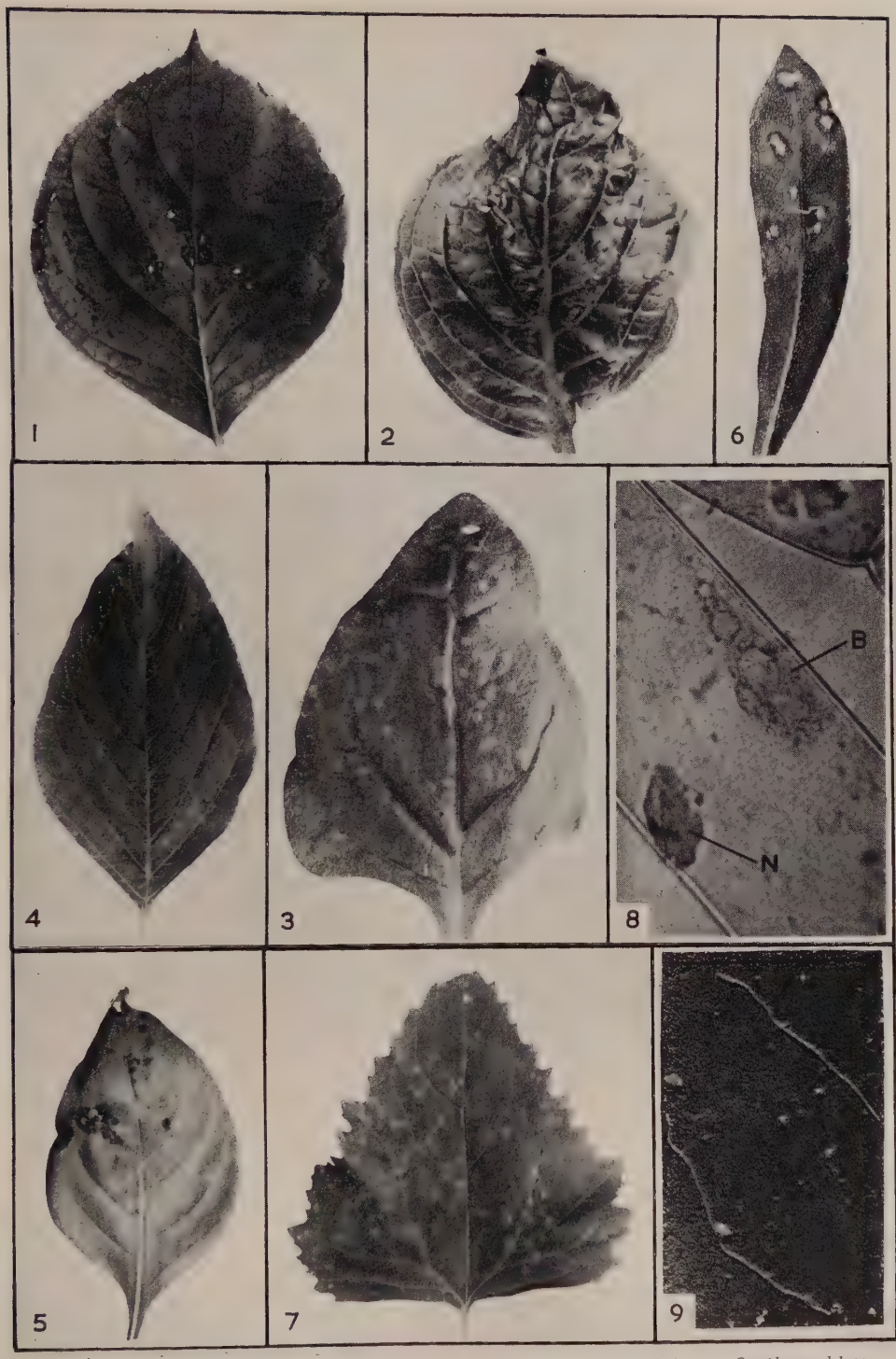

Fig. 1. Chlorotic blotches and necrotic spots on hydrangea (var. Holdstein) leaves.

Fig. 2. Chlorotic spots and rings, slight buckling and distortion of hydrangea leaf.

Fig. 3. Local semi-necrotic spots and small rings on *Tetragonia expansa*.

Fig. 4. Local chlorotic spots on *Amaranthus caudatus*.

Fig. 5. Reddish local necrotic lesions on *Celosia argentea*.

Fig. 6. Local necrotic lesions on *Gomphrena globosa*.

Fig. 7. Local chlorotic dots, each with central necrotic speck, on *Chenopodium amaranticolor*.

Fig. 8. Vacuolate intracellular inclusion in leaf-hair cell of infected *Primula malacoides*.
B = inclusion body; N = nucleus.

Fig. 9. Electron microgram of hydrangea sap, showing rods associated with infection by hydrangea ringspot virus.

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The virus withstood dilution to 1/10,000–1/40,000 according to the tissue from which sap came, heating to 70° C. for 10 minutes, and storage at 18° C. for 21–28 days. Expressed sap stored at 1° C. was still infective after 17 weeks, and freeze-dried infected *Primula* leaves for at least 8 months.

Infective sap contained rods 870–1,400 mμ long and 16 mμ wide. Hair cells of infected *Primula* plants contained vacuolate intracellular inclusions.

An antiserum, prepared by injecting rabbits with partially purified virus preparations, precipitated specifically with sap from infected plants in tube and micro-drop tests, but not in gel-diffusion tests. The virus was serologically unrelated to potato virus X and did not protect plants against it.

ACKNOWLEDGMENTS.

I should like to thank Mr. H. L. Nixon, of Rothamsted Experimental Station, who kindly ultra-centrifuged the preparations for making the antiserum, and for the electron micrograms.

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HEAT TREATMENT FOR THE INACTIVATION OF STRAWBERRY VIRUSES

By A. F. POSNETTE and R. CROPLEY
East Malling Research Station, Kent

SINCE previous publications from the Station on the heat inactivation of strawberry viruses (1953), the treatment has been applied to twenty commercial varieties with varying success. This paper considers some of the factors influencing these results.

EXPERIMENTAL METHODS.

Incubator for heat treatment.

After preliminary trials in ovens and propagation frames, an incubator was constructed which relied on convection to carry hot air from tubular electric heaters into the plant chamber where it was dispersed by a fan. Although this method maintained a constant temperature at any one point, there was variation of several degrees between different parts of the chamber. The heating system was therefore modified by fitting a constant-running centrifugal fan at one end to blow air over the heaters and into the chamber ; the air was then drawn out through the eye of the fan and constantly re-circulated (Fig. 1). By tapering the inlet slot so that it was narrowest near the fan and widest at the opposite end of the chamber, an even distribution of warm air and thermostatic control within 2° C. were attained.

Fluorescent strip lighting was used during the winter months for long periods of treatment, but extra light seemed unnecessary for periods under two weeks.

Plant survival.

Further experience has amply confirmed the earlier recommendation that plants should be well established in pots before treatment and that watering should be kept to the minimum needed to prevent wilting. It has been found deleterious to remove the older leaves ; in experiments with four varieties intact plants invariably survived longer than plants thus defoliated (Table I). The use of plastic pots to avoid the evaporation that occurs from the surface of clay pots also affected survival adversely.

Great differences were noted between varieties in their tolerance of heat. Some, such as Cambridge Forerunner and Cambridge Rival, survived with little injury for six weeks at 37° C. ; others, like Perle de Prague and Early Cambridge, were severely damaged after two weeks.

EXPERIMENTAL RESULTS.

Inactivation of mottle virus.

Many strains of the short-persistence virus designated virus 1 or mild crinkle by Prentice and Harris (1946), and now more usually called mottle, have recently been described (Frazier and Posnette, 1958). The treated plants of the varieties

Table I.

Effect of removing old leaves from plants before heat treatment at 37° C.

Variety	Leaves	Days treated	No. survived out of 5
Cambridge Profusion	Removed	7	0
	Intact	12	5
Cambridge Early Pine	Removed	14	0
	Intact	14	4
Sutton Valence I	Removed	7	0
	Intact	12	2
Jucunda	Removed	12	0
	Intact	12	2

listed in Table II contained different virus strains varying in virulence from the severe curly dwarf ("*X*") to the mild strains that cause only a faint mottle on *Fragaria vesca*. They probably differ in resistance to heat, but no proof of this was obtained when two strains of mottle were compared in a clone of *Fragaria vesca*. Virus inactivation occurred so erratically, however, that interpretation of the results in terms of time and temperature seems impossible. In some experiments virus inactivation, as measured by the proportion of plants that were still virus-free 18 months later, increased with the duration of the heat treatment, but in others this

Table II.

Elimination of mottle virus from plants of 20 varieties by treatment at 36–37° C.

Variety	Days treated	No. plants	No. survived	No. without mottle virus	*Nuclear stock No.
Cambridge Brilliant	24	10	2	2	
Cambridge Early Pine	14	5	4	1	
Cambridge Favourite	17	10	9	4	M410
Cambridge Forerunner	34	5	4	4	
Cambridge Premier	17	10	10	10	
Cambridge Prizewinner	14	10	2	1	M412
Cambridge Profusion	12	5	5	3	
Cambridge Rearguard	10	30	13	13	M409
Cambridge Rival	37	10	8	6	M419
Cambridge Sentry	22	8	5	3	
Cambridge Seedling 620	18	9	4	3	
Early Cambridge	8	7	1	1	M407
Huxley's Giant	9	10	9	8	M403
Jucunda	12	5	2	1	M418
Madame Lefebvre	9	10	8	7	M406
Sir J. Paxton A	9	10	6	1	M416
Sir J. Paxton B	16	3	3	2	
Perle de Prague	6	10	3	1	M404
Spangsbjerg Ydun	35	5	4	3	
Surprise des Halles	35	5	2	1	

* Index number of clone issued for Special Stock propagation.

was not so (cf. Huxley's Giant and Perle de Prague in Table III). Furthermore, a single virus isolate was more readily inactivated in one host than in another ; the virus in Perle de Prague was inactivated in a few plants by treatment as short as 6 days, and 7 to 8 days cured a high proportion of plants ; when the same virus was transferred by aphids to *Fragaria vesca* plants, much longer treatment was required to cure them (Table III).

TABLE III.

Effect of variety and duration on inactivation of mottle virus in plants maintained at 37° C.

Variety	Days treated	No. plants	No. survivors	No. free from mottle virus
Huxley's Giant	6	5	4	0
	7	5	5	0
	8	11	9	6
	9	11	9	6
	10	11	9	8
Perle de Prague	7	10	8	6
	8	10	9	7
	9	10	5	0
Fragaria vesca (infected from Perle de Prague)	7	12	10	0
	9	8	8	1
	18	12	5	2
	26	10	8	3

In these experiments plants of commercial varieties were tested for virus infection by stolon-grafting to *Fragaria vesca* plants. No plants found to be healthy when tested 4 or more months after treatment have indicated a " resurgence " of the mottle virus in subsequent tests over several years. One plant of *F. vesca*, however, developed symptoms after appearing healthy for 5 months after treatment. Many *F. vesca* plants have remained symptomless for 3 months after treatment and then relapsed, whereas the usual period between first infection (by aphids or grafts) and the appearance of symptoms on large plants is seldom more than 3 weeks.

Inactivation of crinkle virus.

Experiments on plants infected with crinkle virus (virus 3 of Prentice, 1940) have suggested that some strains are more readily inactivated than others. Plants of Huxley's Giant were freed from crinkle virus by 9 days at 37° C., but the virus in Cambridge Favourite has resisted 40 days' treatment ; apparently virus-free plants of Cambridge Premier and Cambridge Favourite resulted from 40 and 50 days' treatment respectively (Table IV). The health of these latter plants, however, is still suspect, because, although they were indexed over one year after treatment, the leaf-grafting technique used is now known to be unreliable (Cropley, 1958).

An apparently virus-free plant of Cambridge Favourite was raised from an axillary bud excised from the stem of a plant after 24 days at 37° C. The parent plant proved to be infected, as did axillary buds excised from three other treated plants and similarly rooted by sand culture. The plant derived from this one

Table IV.

Experiments on the inactivation of crinkle virus in plants maintained at 37° C.

Variety	Days treated	No. plants	No. survived	No. without crinkle virus†
Cambridge Favourite	17	6	3	0
	17	10	7	0
	19	9	3	0
	25	7	3	0
	30–40	10	6	0
	50	8	5	3
	24	7	4*	1
Cambridge Premier	17	10	4	0
	22	10	5	0
	40	5	3	1

* Grown from axillary buds excised from plants treated for 24 days.
† See text for reservations regarding freedom from crinkle virus 3.

axillary bud was stolon-grafted to a *F. vesca* plant 8 months later ; they remained united for 2 months and after 6 months no symptoms have developed on the indicator, although others grafted on the same day showed crinkle symptoms within 2 months.

Inactivation of other viruses.

As none of the commercial varieties with which we have worked is totally infected with the yellow edge virus (Prentice, 1948), there is no immediate call for its inactivation. From the experiments carried out so far, however, it seems probable that the virus is not readily eliminated by heat therapy. Royal Sovereign plants infected with yellow edge virus have not been cured by periods up to 26 days at 37° C. ; although some plants have remained symptomless for more than a year after treatment, they have eventually relapsed. A runner plant that was propagated immediately after the parent had been treated for 16 days was apparently virus-free when grafted to *F. vesca* 2 years later, although others were infected (Fig. 2).

Vein chlorosis virus (virus 4 of Prentice, 1952) has recently been detected in clones that were previously thought to contain only the strawberry latent A virus (Frazier, 1953). Until an indicator more sensitive than the East Malling clone of *F. vesca* had been developed, critical work on the inactivation of virus 4 was not possible. Selection among *F. vesca* seedlings has now provided a suitable indicator clone, and it is already clear that virus 4 is at least as difficult to inactivate as the crinkle virus.

DISCUSSION.

The application of heat therapy to virus diseases of strawberry has considerably reduced the danger of permanent degeneration of varieties through virus infection. Ten varieties now propagated by the Nuclear Stock Association (Harris, 1955) for the Special Stock Certificate have been heat-treated. Some of them require further treatment to eliminate latent A virus and also, with at least two varieties, the vein chlorosis virus. Prior to 1952, when heat-treated clones were first introduced, only two commercially-grown varieties in Britain were represented by stock of comparable health.

The full benefit of healthy planting material to the fruitgrower cannot be assessed for some years. Some varieties when virus-free may prove too vigorous when grown under traditional management, and economy in fertilizers may be important in reducing both costs and loss from *Botrytis* rot (Rogers and Fromow, 1958). It seems unlikely that the weight of fruit obtained from a virus-free plant of a tolerant variety will exceed that from plants carrying only a latent virus, so long as no other viruses spread into the crop. Under conditions where yellow edge and crinkle viruses spread rapidly, however, the originally virus-free plants would degenerate more slowly than those already infected with a mild virus when planted.

None of the strawberry viruses is as suitable as tobacco necrosis virus (Harrison, 1956) for investigating the effects of temperature on virus multiplication and inactivation, because at present there is no technique for assaying viruses that are not sap transmissible. Transmission tests with aphids suggest that heat treatment at first greatly reduced the virus content of plants that were not permanently cured. Many plants from which aphids failed to transmit a few weeks after treatment were later found to be as suitable sources of virus as the untreated control plants ; but the interval between heat treatment and the redevelopment of symptoms was much longer than the usual incubation period observed when healthy plants are infected for the first time. The reason for this delay in symptom development, which occurred with mottle, crinkle and yellow edge viruses, and was also noted with apple mosaic virus (Posnette and Cropley, 1956), may be the survival of active virus only in deep-seated tissues in the stele from which translocation is slow. If so, it should not be difficult to propagate healthy plants from stolons or axillary buds excised from the stem before they become re-invaded by the virus. The limited success achieved by us with this method suggests that the protracted incubation period may be due, not to localized infection, but to a prolonged suppression of the virus at a low concentration throughout the body of the plant. It is tempting to speculate that either inactivated virus or a substance broadly analogous to antibodies is suppressing normal virus synthesis, but the similarity between the prolonged incubation period in heat-treated plants and that observed when related virus strains exhibit partial cross-protection suggests a more probable interpretation : that avirulent strains more tolerant of heat replace and temporarily suppress the pathogenic strains that can be detected because they induce symptoms on the indicator plants. Holmes (1934) and Kassanis (1957b) found attenuated strains of tobacco mosaic virus that multiplied at a higher temperature than the virulent strain. Our hypothesis can be tested by re-inoculating plants immediately after heat treatment and comparing the incubation period in those which were infected with that in plants which were healthy before they were heated. The prolongation of the incubation period of strawberry viruses seems worthy of further investigation because it directly affects the production of virus-free material by propagation from treated plants that are only temporarily cured, and also because, if observed, it has not been reported in other investigations reviewed recently by Kassanis (1957a).

SUMMARY.

In experiments on the inactivation of strawberry viruses, potted plants were maintained for periods up to 50 days at 37° C. Plants of twenty varieties were freed from mottle virus by treatment for various periods, the shortest being 6 days for

PLATE I

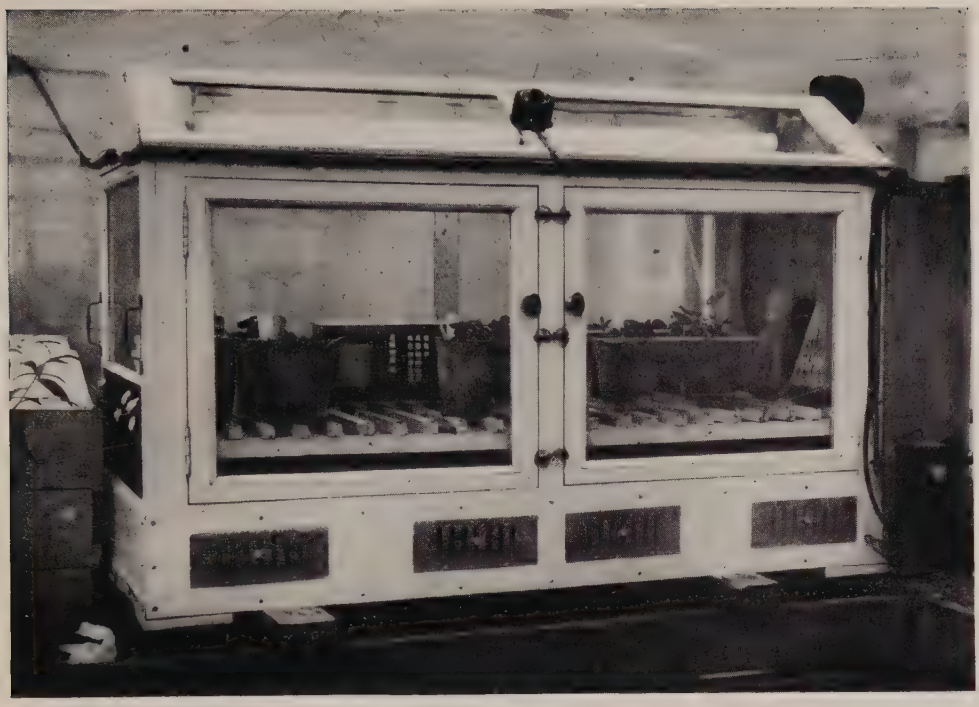

Fig. 1.
The constant temperature apparatus.

Fig. 2.
Royal Sovereign plants of a clone originally infected with yellow edge virus.
Left : a runner propagated from a plant heat-treated a year previously ;
right : a runner propagated from an untreated plant.

[*face p. 286*

Perle de Prague. Varieties differed in the period required for permanent virus inactivation and this variation was attributed to varietal differences and probably to virus strains differing in heat tolerance.

Crinkle and yellow edge viruses are more difficult to eliminate than mottle. With crinkle, treatment at 37° C. for periods of 30 to 50 days appears to have been effective ; with yellow edge, the corresponding period was 26 days.

After heat treatment, plants that were not permanently cured frequently remained symptomless and without transmissible virus much longer than the normal incubation period of the viruses present. It is suggested that this might be due to partial cross-protection by avirulent strains that have been less affected than the pathogenic strains by the heat treatment.

ACKNOWLEDGMENTS.

We are indebted to Miss C. E. Ellenberger for much assistance in the glasshouse. The photographs were taken by Mr. E. Yoxall Jones.

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QUINCE INDICATORS FOR PEAR VIRUSES

By A. F. POSNETTE and R. CROPLEY
East Malling Research Station, Kent

THE symptoms of some virus diseases of pears and the use of quince to detect latent viruses have already been reported (Posnette, 1957). Further experiments have evaluated the indicator clones derived from seedlings of Quince E (Portugal Quince) and shown the presence of two viruses that cause symptoms not previously described.

Quince indicator clones.

The clones C7/1 and C7/2 were selected from among open-pollinated seedlings of Quince E and propagated by budding on Quince A rootstocks. The first attempts to obtain rooted cuttings of C7/1 and C7/2 failed but, as no virus has been detected in the Research Station's stoolbeds of Quince A, this rootstock has probably not influenced the reaction of the indicator clones to virus infection.

Experiments already described (*loc. cit.*) showed that Quince E, C7/1 and C7/2 behaved similarly when budded on to infected quince stocks, the reaction depending on the virus present. Subsequent tests have confirmed that quince stunt virus kills the indicator buds, sooty ring spot virus causes early death of the scion growth in the spring, and pear mosaic virus induces chlorotic ring and line patterns on the leaves of these quinces.

When one-year-old plants of C7/1 and C7/2 on Quince A roots were inoculated in the summer by budding with bark patches infected with either quince stunt or sooty ring spot virus, characteristic leaf symptoms developed in the following year (Fig. 1). Quince stunt caused leaf puckering with yellow chlorotic spots, and sooty ring spot downward curling of the leaves and veinlet chlorosis followed by the sooty mould-like pigmentation previously illustrated (*loc. cit.*).

Symptoms on both clones were similar but C7/1 is preferred as an indicator because it grows more erect and is less susceptible than C7/2 to mildew. Symptoms on Quince E were of the same type but were more localized and developed more slowly than on the C7 clones.

Yellow blotch virus.

The C7 clones were used to index pear scionwood of commercial varieties from many different sources, including the National Fruit Trials at Wisley, Long Ashton Research Station, John Innes Horticultural Institution and East Malling. Most of the source trees were found to be infected with one or more of the viruses previously described, but two trees of Packham's Triumph were infected with a virus that caused diffuse yellow blotches on the leaves of C7/1 and C7/2 (Fig. 2). These symptoms developed in the spring after summer inoculation, persisted throughout the growing season, and recurred in the second year. Nursery trees of Packham's Triumph,

propagated from the same sources, showed no symptoms other than those of the widespread vein yellows virus that causes no symptoms on quince. They have not yet fruited, but the parent trees have borne the irregularly-shaped pears characteristic of the variety. Whether the " bumpy " fruit of Packham's Triumph is a genetic character or a disease symptom is not known. It may, however, be significant that, of many varieties tested, Packham's Triumph alone contained this yellow blotch virus.

Bark necrosis virus.

Two years after pear bark patches had been grafted into Quince E seedlings, many of the latter were found to have zones of necrosis in the bark around the patches (Fig. 3). The seedlings differed greatly in the extent of the necrosis ; on some it was confined to the immediate vicinity of the patch while in others it had spread several inches above and below the patch. The distribution of the disease among the quince seedlings showed that certain sources of the pear scions in each of the varieties tested (Beurré Hardy, Williams' bon Chrétien and Clapp's Favourite) were pathogenic and others were not. No fungal or bacterial pathogens could be isolated from the necrotic zone and none could be seen in microscopic preparations. The necrosis could not be attributed to infection with viruses previously found in pear ; two sources apparently free from all these viruses induced bark necrosis in quince.

Transmission tests were made on the C7 quince varieties. Quince A rootstocks were budded with C7/1 and C7/2, and buds of pear from sources that caused the necrosis on quince seedlings were inserted on the stocks about 3 inches below the indicator buds. The latter were grown as normal scions, but growth from the pear buds was rubbed off. After one growing season, the bark of the quince indicators was seen to be split and roughened, especially near the union with the rootstock (Fig. 4). The controls, C7/1 and C7/2 on Quince A without pear bud inoculations, had smooth bark. Furthermore, this abnormal bark has not developed on any of the 50 uninoculated plants of the C7 clones propagated on Quince A rootstocks.

Three-year-old pear trees known to be infected with bark necrosis virus were compared with others believed to be free from it. No bark necrosis was found on either the scion or the Quince A stocks beneath them, but some of the pear seedling stocks under infected scions had roughened bark (Fig. 5). The distribution suggested that some seedlings were sensitive and others tolerant, as was observed with the quince seedlings on which necrosis was first noticed.

DISCUSSION.

The quince clones C7/1 and C7/2 have fulfilled their promise as indicators for virus diseases of pears. At present there seems no reason to continue to use both, and C7/2 will be held in reserve in case C7/1 should develop some undesirable feature ; one budded plant has a genetical variegation and this may become more prevalent as the clone ages.

Of the two viruses reported in this paper, yellow blotch is apparently rare in England and may even be confined to the variety Packham's Triumph which was introduced in recent years from South Africa. Scionwood received direct from South Africa is now being tested, primarily to secure a virus-free source of the variety, but the tests may also indicate the origin of the yellow blotch virus.

PLATE I

Fig. 1.
Symptoms of quince stunt (*left*) and sooty ring spot (*right*) viruses in Quince C7/1.

Fig. 2.
Symptoms of yellow blotch virus in Quince C7/1.

[*face p.* 290

PLATE II

FIG. 3.
Quince E seedlings with bark patches of Williams' Bon Chrétien, healthy (*left*) and with bark necrosis virus (*right*).

FIG. 4. FIG. 5.

FIG. 4.
One-year-old Quince C7/1 on Quince A with bark patch of Dr. Jules Guyot pear infected with bark necrosis virus. Note rough bark on C7/1 stem.

FIG. 5.
Rough bark on pear seedling below graft-union with Clapp's Favourite pear infected with bark necrosis virus.

Bark necrosis virus is widespread in the pear material indexed, both from English and from French sources. Although there is little evidence to associate this virus with any bark diseases of pear such as " oak bark " (Kienholz, 1939), it must restrict the number of quince and pear clones that can be used as rootstocks for pears. A sensitive rootstock would soon become " ring barked " by necrosis below the graft union with an infected pear scion, and the union would probably be weak because of restricted growth where the pear and quince tissues were in contact. Quince A and the pears Beurré Hardy, Clapp's Favourite and Williams' bon Chrétien seem to be tolerant, at least when young, but this tolerance *may* be found to decrease with age and unfavourable conditions, and so lead to the unhealthy state of the bark commonly seen on orchard trees of these varieties.

SUMMARY.

Two quince clones, propagated from seedlings of Quince E (Portugal Quince) have proved to be suitable indicators for the viruses latent in pear. By their use two viruses, in addition to those previously described, were identified in pear varieties. Yellow blotch virus occurred only in Packham's Triumph pear, but bark necrosis virus was found in several varieties including Clapp's Favourite, Beurré Hardy and Williams' bon Chrétien.

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BOOK REVIEWS

EXPERIMENTAL HORTICULTURE No. 1. Ministry of Agriculture publication. (London : H.M. Stationery Office. 1958. Pp. 59. Price 3s. 6d.)

The first number of this new journal dealing with experimental work carried on by officers of the National Agricultural Advisory Service is sure of a warm reception. For some time " Experimental Husbandry " has been covering the investigations of interest to farmers, and the new journal reports in a similar way on experiments concerned with fruit, vegetables, flowers, and crops under glass. It is intended chiefly for commercial growers and advisory officers, but judging by the standard set in the first number it should prove of real value to research workers and students also.

The investigations described have been conducted at the Experimental Horticulture Stations of the N.A.A.S., and on commercial holdings by the county and regional advisory officers. New work of a similar nature carried out at research stations, universities and other institutions will be included from time to time in future numbers. It is probably fortuitous that fruit figures so largely in the first number, with papers on the National Fruit Trials, orchard swards, herbicides in strawberries, strawberry and raspberry varieties, and pest control, compared with only three papers on other aspects of horticulture, glasshouse heating, chrysanthemums and rhubarb. No doubt the balance will be adjusted in following issues.

H.B.S.M.

PUBLICATIONS RECEIVED.

HANDBOOK OF CITRUS DISEASES IN FLORIDA. By L. C. Knorr, R. F. Suit, and E. P. Ducharme. Bulletin University of Florida Agricultural Experiment Station, No. 587. 1957. Pp. 157, illus.

This handbook describes the symptoms, causes and control of citrus diseases in the widest sense, including troubles due to frost and water logging, certain nutrient deficiencies, parasitic plants, nematodes and even 2,4-D, as well as those caused by fungi, bacteria and viruses.

REPORT ON FRUIT TRIALS IN SCOTLAND, 1949–56. Scottish Agricultural Improvements Council, Fruit Trials Committee. (Obtainable from Scottish Horticultural Research Institute, Mylnefield, Invergowrie, By Dundee. 1957. Price 2s.)

This is the first report of the Fruit Trials Sub-committee set up in 1949. It includes accounts of variety trials of raspberries, strawberries and black currants at Mylnefield and the three Scottish Agricultural Colleges over a four-year period 1953–6.

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